Skin color and facial prosthetics

-a colorimetric study-

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Stellingen behorende bij het proefschrift

"Skin color and facial prosthetics"

I

Verpulverd phototroop glasmateriaal gedispergeerd in de buitenste laag van een Silastic^{R} gelaatsprothese zal mogelijk een variatie in de prothesekleur kunnen geven die overeenkomt met de huidskleurvariaties t.g.v. U.V.- en temperatuursinvloeden.

G. Guilino, et al., Deutsche Optiker Zeitung, 9:1978
Hoofdstuk 6 van dit proefschrift

II

De psychosociale problemen bij een gelaatsgehandicapte kunnen worden gereduceerd door een procesbegeleider in de multidisciplinaire werkgroep op te nemen, die inzicht heeft in alle facetten van het ablatie- en rehabilitatieproces, komend uit de medisch maatschappelijkwerk discipline.

Hoofdstuk 2 van dit proefschrift

III

Uit het onderzoek van de Gruyl kan worden geconcludeerd dat de ontvankelijkheid voor het ontstaan van door ultraviolet licht geïnduceerde huidtumoren samenhangt met de dikte van de epidermis.

F.R. de Gruyl, Proefschrift, Utrecht, 1982

IV

De invloed van fouten, die ontstaan bij het meten van reflectie aan translucente materialen, die veroorzaakt worden door lichtlek in het meetobject, kunnen voorkomen worden door de diameter van de meetopening van de reflectometer aan te passen aan de verstrooiingscoëfficiënt van het object.

R.A.J. Groenhuis, Proefschrift, Groningen, 1981

V

Voor het onderzoek van aandoeningen van de grote speekselklieren dient, voor het verkrijgen van voldoende informatie, zowel computertomografie als gewone sialografie te worden toegepast.

B.L. Carter, et al., J.Comp.Assisted Tomography, 1:46-53, 1981

VI

De prijs van wetenschappelijke informatie is een belangrijke hinderpaal voor werkelijke internationale universitaire samenwerking met de Derde Wereld.

Overzicht, sept. 1981 (Nuffic uitgave)

VII

De zelfwerkzaamheid, als onderdeel van een individueel studiesysteem in het tandheelkundige practicum, moet gesteund worden door een begeleidend docent, die de student helpt zijn problemen te verduidelijken en aan hem op de juiste momenten zijn psycho-motorische vaardigheden etaleert.

VIII

Het maatschappelijk bestel heeft behoefte aan meetinstrumenten die de grenzen van het optimaal functioneren en, bij overschrijding daarvan het in werking treden van het "Peter principle", kunnen vaststellen.

IX

Het op grotere schaal stimuleren van de bewegingsactivering en reactivering van oudere mensen onder bekwame leiding, bevordert het welzijn van deze bevolkingsgroep, vermindert de kosten van de gezondheidszorg en heeft tevens een positief effekt op de werkgelegenheid.

X

Ook zonder wettelijke verplichting is post-academisch onderwijs voor werkers in de gezondheidszorg niet vrijblijvend.

XI

Bij een fusie van scholen moeten de persoonlijke en rechtspositionele kondities van de betrokken onderwijsgevenden in de aanvang van het fusieproces reeds voldoende aandacht krijgen om een inhoudelijke vernieuwing van het onderwijsproces voldoende kansen te geven.

B. Fonderie, B. Rümke, Meso 4/mei, 1981

XII

Voor een optimale behandeling van patiënten met brandwonden is naast een goed funktionerend brandwondencentrum, de communicatie van een dergelijk centrum met de eerstehulpverleners van het grootste belang.

XIII

De CO_2laser is bij uitstek geschikt voor oppervlakkige verdamping van weefsel, gebruikt als "lichtmes" heeft het geen voordelen boven het "elektrisch mes".

P.P. Lunkenheimer, et al., Laser Surgery, Jerusalem Academic Press, 334-350, 1978

XIV

Roken tijdens vergaderingen in ruimten met onvoldoende luchtverfrissing is een vorm van fysieke en mentale intimidatie, zowel van de rokers als de niet-rokers.

XV

De groenstroken langs de fietspaden in Beijum dienen in verband met de heersende windrichting aan de westzijde voorzien te zijn van altijd groene heesters.

XVI

Het feminisme is, en het hominisme wordt uit een nood geboren en beiden zullen weer tot elkaar komen.

Groningen, 31 maart 1982 R.P. van Oort

Rijksuniversiteit te Groningen

SKIN COLOR AND FACIAL PROSTHETICS

Proefschrift

ter verkrijging van het doctoraat in de
geneeskunde
aan de Rijksuniversiteit te Groningen
op gezag van de Rector Magnificus Dr. L.J. Engels
in het openbaar te verdedigen
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4.00 uur

door

Robert Piet van Oort
geboren te Gorinchem

krips repro meppel

Promotor : Prof. Dr. J.J. ten Bosch
Co-promotor: Prof. Dr. E. Bleumink
Coreferent : Prof. Dr. G. Boering
Prof. Dr. A.C.M. van de Poel

Paranimfen: Peter Borsboom
Hans van Pelt

It is to be hoped that the
time is not too distant when
the public, through information and education
will understand more fully
the plight of one who has
a marred or a typical face
and will not add to his difficulties
either by rejection or by unsought
sympathy.

Frances Cooke MacGregor

Aan mijn Ouders
Aan Riet
Inge Mariël
Bart Remy
Nils Erik

CONTENTS

CHAPTER 1

INTRODUCTION AND AIMS OF THE INVESTIGATION

A person afflicted to missing a part about the face is stigmatized and confronted by a social and personal crisis. The face determines many aspects in the whole gamut of human encounters, such as social and play interactions, employment opportunities and psychosocial determinations. The problems this poses to the patient are centered around the psychological adjustment to the social consequences of the disfigured face.

The clinical investigations of MacGregor (1951 and 1979) threw light upon the role of selfconcept, the patients sensitivity to bodily impairment and the ways in which maxillofacial problems influence social interactions. According to MacGregor the major aims of the rehabilitation must be geared to

firstly : The reconstruction of the face, in order to obtain an approximation of a normal face, and

secondly: The prevention of potentially devastating social and psychological consequences.

These two aspects are closely related because the psychosocial problems of the patient are strongly affected by a plastic surgical treatment or a maxillofacial prosthetic treatment of a mutilated face. The surgical reconstruction has the advantage of being a replacement of missing tissue by one's own skin. This corrective procedure gains more easily acceptance for the patient as part of his body than a prosthetic foreign device. A prosthetic reconstruction will remind the patient of his handicap by the every-day care of the facial prosthesis together with the feeling of being ostentatiously disabled (Fig. 1.1, 1.2, 1.3).

Figure 1.1
Patient with a history of squamous cell carcinoma. No immediate reconstruction was chosen to be able to monitor the defect for recurrence.

Figure 1.2
A prosthesis was fabricated. The lines of junctures are mostly hidden by spectacles or are placed into skin creases and folds.

Figure 1.3
Sixteen months of follow-up without recurrence, the defect was subsequently reconstructed with a forehead flap. Plastic surgical operation by dr. E.W. Sauër.

Therefore in general the plastic surgical reconstruction is the first method of choice in the treatment of a disfigured face.

A prosthetic reconstruction is the method of choice in cases of reconstruction of an exenterated- or enucleated orbit and of a total or partial ear reconstruction. It is also indicated after previous cancer surgery and after irradiation and in cases of debilitating physical health (Bulbulian, 1973; Vermey, et al., 1981). In general it gives the most pleasing results.

This study deals with the prosthetic reconstructions of the disfigured face. The problems encountered will be described in chapter 2. The prosthetic reconstruction of a missing part of the face requires a restoration of form, texture and above all color. The different aspects of appearance and its measurement as well as the appearance of the skin are described in the chapters 3 and 4 respectively.

The reproduction of form and texture is acquired by means of technological procedures (Bulbulian, 1973; Beumer, 1979). The color matching of the prosthesis to the skin is important. Several color matching systems have been developed which are based on artistic procedures (Ouelette, 1969; Schaaf, 1970; Bartlett et al., 1971). Other methods are based on internal color characterisation (Fine et al., 1978) and external coloration in situ of a prosthesis which has a standardized internal color (Lontz and Schweiger, 1976). These different methods are time consuming, are difficultly reproducible and are based on subjective color matching for one light condition only. So far no method has been reported, which has been based on an instrumental color measurement of the skin. The ideal system will be the formulation of a matching base color using a spectrophotometer and subsequent computer program for specification of the ratio of pigments and elastomer. This system will be investigated in the near future.

The aim of this investigation is to determine the range of a skin color reproducing system for a population. In this system the colors of the complex dynamic variable multi-layered skin are to be included. More specifically this means that we have to study the following problems.

1. The range of skin color likely to occur in (the north of) the Netherlands.
2. The variation of skin color caused by photobiologic factors.
3. The effect of dermal vascular changes on the skin color due to muscular work and due to temperature changes of the environment.
4. The influence of irradiation on the color of the skin.

To this end the following investigations were carried out:

1. A color measuring method is chosen and adapted for skin determinations. It was applied to the facial skin as well as other skin regions of the body without interfering with the vasculature of the skin.
2. An epidemiological study on skin color is performed in a group of persons, originating from the north of the Netherlands.
3. An investigation of the seasonal variation of skin color is done in a group of persons with comparable social activities as the group of patients with a facial prosthesis.
4. A study of the variation of facial skin color due to muscular work.
5. An investigation on the variation of facial skin color due to environmental cooling.
6. A study of the variation of facial skin color caused by irradiation in the head and neck region.

The results of the investigations are described in the chapters 5, 6 and 7. The presented data will indicate the maximum range of natural occurring skin color variation.

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CHAPTER 2

APPEARANCE OF THE FACIAL PROSTHESIS - STATE OF THE ART

2.1. Abstract

The appearance of the face is important for the self-concept and the social life of a human being. Therefore a disfigured person needs a surgical or prosthetic reconstruction which approximates the "normal" face. The relevant details of prosthetic technology are described. They are aimed at the inconspiciousness of the prosthesis in the face. Several color matching systems are available, which are based on artistic procedures and color shade guides. No systhematic method is available which duplicates skin color based on measured skin color data. For this and other reasons the results of facial prosthetic treatment are not ideal. At the moment the rehabilitation process, may offer the patient some implements for the adaptation to a sometimes far from normal social life.
Further improvements of material, suitable for prosthetic reconstruction pigments and color matching system, as well as improvement in the psychosocial rehabilitation process of the handicapped patients are required.

2.2. Introduction

Facial defects may be caused by treatment of neoplasms, trauma and congenital malformation. The incidence of facial defects is relatively low, 1:100000/year (approximately) for the three northern provinces of the Netherlands.

In the period of 1970 to 1981 one hundred and twenty-three patients with a facial defect were treated prosthetically at the Department of Oral surgery and Maxillofacial Prosthetics of the University of Groningen. They are classified in Table 2.1. For other epidemiological data compare Jani and Schaaf (1978).

Table 2.1. Types, number and causes of facial prosthetic treatment in 123 patients within a period of 11 years (1970-1981)

Type of prosthesis / causes	tumour	trauma	congenital	no of patients	total no of prosthesis
orbital	57	2	2	61	137
nasal (partial + total)	26			26	59
auricular	16	5	2	23	40
combination of facial	12	1		13	25

Increasing awareness of cancer may result in earlier diagnosis and treatment, which will result in an increased survival rate. This may lead to an increasing number of cases with facial tumour treatment. The surgical removal of a facial tumour which leaves a defect in the surface of the skin, should not result in a morbidity which cannot be reconstructed. Therefore preoperative planning must intervene in such a way, that the social life of the patient is as little disturbed as possible.

2.2.1. Limitations of the treatment methods

Restoration of facial defects is a challenge for both the plastic surgeon and the prosthodontist. Surgical reconstructions as well as prosthetic restorations have distinct limitations.

The surgical procedures are limited by the availability of tissue and the condition of the vascular bed. This vascular bed is sometimes in a poor condition due to irradiation and/or a debilitating physical health.

The prosthetic procedures are limited by the availability of materials adequate for facial restoration, the movable supporting tissues, the difficulty in retaining a large prosthesis and by patient-acceptance.

Surgical replacement of a missing part of the face by one's own skin is accepted more easily, although the contour is inferior to a prosthetic reconstruction in most of the cases. Prosthetic treatment offers the advantage of a quick, reversible and medically uncomplicated rehabilitation. A prosthesis produces less anxiety and permits more social readjustment than does a dressing or no prosthesis at all (Chalian et al., 1972; Bulbulian, 1973; Beumer et al., 1979).

2.2.2. Physical retention

A good retention of the prosthesis on the dynamically viable skin is a precondition that determines the adequacy of performance of all other characteristics of the facial prosthesis. Retention involves the appearance, the comfort for the patient, and his adaptation of the prosthesis.

The different methods of retention are described by Fonseca (1966). Most patients may be served best by the use of a suitable adhesive. Selection is based on biocompatibility, ease of applicability, the possibility of daily removal, the type of defect, the presence or absence of perspiration and the material of the prosthesis (Udagama, 1975). A perfect adhesive is not available. For the silastic^{R} material the Hollister^{R} medical adhesive, or the

Epithane-3^{R} adhesive has been selected.

2.2.3. Psychosocial aspects of disfigurement

The face is the organ of verbal and non-verbal communication. The maxillofacial region is important for interpersonal contacts ranging from the most superficial to the most intimate relationships (Bailey and Edwards, 1975). For this reason a disfigured individual will find himself at a serious social disadvantage. His facial characteristics, as perceived by others, distort their judgments about him as well as their communication with him. This may lead to social withdrawal. The gravity of this process depends on personal characteristics, such as the selfconcept and the patients sensitivity to bodily impairment. It depends also on the social life of the individual, his environment, family, friends and vocational associates (MacGregor, 1979). A complicating factor in the patients reactions to disfigurement is his fear and anxiety of cancer (Turns and Sands, 1978; Sela and Löwenthal, 1980). Such a social rejection and cancerofobia complicates the expected process of rehabilitation in this crucial stage of his life. This expected rehabilitation may fill the patient with feelings of uncertainty about alterations in modes of expressive behaviour (Bailey and Edwards, 1975).

On the other hand patients may develop unrealistic expectations about prosthetic treatment and this may lead to negative attitudes toward the resulting maxillofacial prosthesis. Another type of patient may concentrate on the potential disadvantages of wearing an artificial substitute. In an evaluation report of 76 patients with facial prosthesis (Jani and Schaaf, 1978) 44 of the respondents were not using their prosthesis continuously. They had physically or prosthetically reasons for not wearing the prosthesis.

Several investigators found no simple relationship between the severity of facial disfigurement and the psychological strain on the patient (MacGregor, 1979; Rozen et al.,

1972; Sykes et al., 1972; Roefs et al., 1982). It has been observed that a prostheses with a perfect configuration not always eliminates the psychological distress of the patient. A complete understanding of the rehabilitation process requires the answer to the following questions: Is there any relation between personality type and the rehabilitative response? How important is the family structure? Is the level of patient education and his social class important? (Gilles et al., 1979).

In practice several factors are important in the rehabilitation process.

1. In the initial stages the patient should be allowed to mourn the loss of a part of the body. Kübler Ross (1969) experienced that denial for the reality of the patient mortality is unhealthy for the patients acceptance of the situation.
2. The patient-doctor relationship based on an empathic mutual respect and confidence gives the process of readjustment to society a favourable prognosis (Frank, 1975).
3. Before and after discharge considerations should be given to the patients relatives. The opportunity to discuss the problems concerning the prosthesis or any other related problem should be offered (Addison, 1975). Institutional help by the social worker should be available if the patient needs it. However moral support by his family or relatives is preferable (Molier-van Duyn, 1981).

The challenge to the maxillofacial-prosthetist is to relieve the psychological trauma of the patient with a facial defect by manufacturing an esthetically pleasing restoration of the lost facial organ with respect to contour texture and above all, color. This may facilitate the reinstatement of the patient in society.

The different aspects which determine how inconspicious the facial prosthesis is, can be divided into factors independent of time, related to the restoration of contour and

texture, and time dependent aspects related to the facial tissue and prosthetic materials used.

2.3. Time independent aspects of appearance

2.3.1. Restoration of contour

Surgical techniques combined with irradiation therapy may leave large defects that demand the restoration of contour and texture of the particular facial area concerned. The impression, cast, modelling, and investment techniques have been described with great detail and accuracy by Roberts (1971), Chalian et al. (1972), Bulbulian (1973) and Udagama (1977) and others. It is up to the individual prosthetist to choose his own technique, that depends on the laboratory facilities.

Removal of adjacent subcutaneous tissue of a relatively small surface defect, as this may occur in case of an exenterated orbit or resection of the cartilage areas of the nose, leaves the prosthetist with a difficult choice. He may choose for a rehabilitation plan which will restore the facial symmetry, or he may choose for concealment of the facial defect, without restoration of the symmetry, making use of the camouflage possiblities of spectacles, eyebrow or moustache. A larger facial prosthesis may have the negative side effect that its bulk may make it more obvious. This decision requires the knowledge or correct appraisal of the psychological condition of the patient (Conroy et al., 1975).

The prosthetic restoration of the facial contour sometimes requires surgical modifications to create an external ear canal, to remove scar tissues, to improve the hairline, to alter the configuration of the facial defect, to reduce it in size, or to control the flow of nasal and oral secretions. A unilateral remnant of the nasal ala, after a partial rhinectomy, may prevent a correct reconstruction of the

facial contour. Residual tissue remnants of the ear have no retentive value and may prevent sculpture and positioning of a prosthetic ear.

The quality of the rehabilitative procedure depends in general upon the cooperation between the patient, the oncology-surgeon, the ear nose and throat-surgeon, the plastic-surgeon, the oral-surgeon, the nurse, the oral hygienist, the maxillofacial prosthetist, the social worker and the laboratory technician. This cooperation is needed before, during and after the operation.

2.3.2. Reproduction of texture of the adjacent skin

The reproduction of texture of the skin requires the restoration in both amount as well as quality of surface reflection of light. Various attempts to achieve a lifelike reproduction of skin with respect to wrinkles and grooves have been described. A gauze moistened with xylene was used to press on the surface of the prosthesis covered with an auto-catalytic elastomer (Ouelette, 1969). Spraying of a catalyst on the surface of the prosthesis was done by Firtell (Firtell et al., 1969). Duplication of the texture of an adjacent skin area in a thin layer of latex, which was stretched over the wax prosthesis was done by Hawkinson (1965). Aina (1978) has described a method of reproducing skin texture. This was accomplished by means of a silicone impression of the skin surface of the same, or the contralateral side of the face. The silicone impression was used as a mould to press on to the softened surface of the waxed prosthesis. These techniques only have the desired effect when the internal coloring of the prosthesis is sufficient. If additional external coloring is added, surface detail produced by the impression technique may be lost.

Tactility of the prosthesis material, defined by the coefficient of friction and hardness, should resemble the surface properties of the skin (Lewis and Castleberry, 1979).

2.3.3. The margins of the prosthesis

The inconspicuousness of a facial prosthesis is also influenced by the visibility of the margins of the prosthesis (Fig. 2.1 and 2.2.).

Figure 2.1

Patient with a history of squamous cell carcinoma with recurrence 10 months after initial radiotherapy treatment. The picture shows the result after rhinectomie with extension down into the lip

Figure 2.2

In this nasal prosthesis the lateral line of juncture is less conspicuous because of the feathered margins. The caudal line of juncture was covered with a moustache

A blunt edge is more visibly than a feather edge construction. The ability to produce a feather edge depends mainly on the mechanical and physical properties of the material used. Desirable ranges of these properties are described by Lewis and Castleberry (1979).

2.4. Time dependent aspects of appearance

The conspicuousness of a prostheses is related to the lost physiological properties and anatomy of the defect area, the tissue bed on which the prosthesis is situated and the color and gloss of the adjacent dynamic variable skin, relative to the prosthesis.

2.4.1. The physiology of the defect area

Several physiological factors cannot be reconstructed prosthetically. The mobility of the eye and eyelid, as well as the lower- and upperlip is difficult to reconstruct.

The immobility of the prosthetic eye, eyelid and a prosthetically reconstructed upperlip is perceived immediately on intimate distance (30-45 cm) as well as on personal distance (60-120 cm) as being abnormal (Hall, 1969). However viewed at public distance (120 cm) it may be acceptable.

Spectacles for the eye or an artificial moustache for the lip shortens the distance level of perception and increases the degree of inconspicuousness (Fig. 2.3.).

Figure 2.3
Only small segments of the line of juncture of the nasal prosthesis are observable. Most are hidden by spectacles or covered by a moustache.

Aryeli (1976) has described a technological innovation in making a movable upper eyelid. This eyelid was simultaneously movable with the contralateral one. The micro-electro-

nic technology used in this construction may improve this procedure in the near future.

The prosthetic reconstruction of the lower lip is contra-indicated because of impairment of function, which causes incontinence of saliva and impairment of swallowing. In the case of an upperlip defect a temporary prosthetic reconstruction after irradiation and surgery may be indicated. This should be followed by a plastic surgical reconstruction as soon as possible.

2.4.2. Color aspects of the prosthesis

Skin color varies with different physiological and pathological conditions, depending on the capillary blood flow and oxygenation, the thickness of the epidermis, and the presence of pigments. From this point of view color matching between skin (color) and prosthesis is a hazardous procedure. The degree of variation in skin color determines the utility of a color matching-procedure, and limits the usability of an accurate color matching system.

A prosthesis may be colored by an internal method, an external method or a combination of both. Several color matching procedures have been described. Chalian and Lontz developed a method of *internal coloring* of heat temperature vulcanized (HTV) silicone material. They used mixed metallic oxides or pigmented silicone concentrates, together with red nylon fibers (Chalian et al., 1972; Chalian and Philips, 1974; Lontz and Schweiger, 1976).

Internal coloring procedures at room temperature have been reported using vulcanized silicone (RTV) (Fine et al., 1978; Chalian, 1979). In this method an opacifier and various dry earth pigments and different color rayon flocks are mixed into a transparent or semi-transparent viscous elastomer material.

The method developed by Fine and coworkers is accomplished by the selection of color shade guides. These guides have differing skin tone formulae which can be used to decide the

intrinsic color characterisation of the prosthesis. Different layers of colored RTV silicone material may be applied to copy the semi-transparent character of the skin. These shade guides can be easily duplicated.

If the internal coloring of the prosthesis fails to match the skin color, *an external coloring* may improve matching. Many procedures have been developed in the past. Bartlett, Pineda and Moore (1971) applied an autocatalytic adhesive silicone thinned with xylene and colored with pigments to the surface of the prosthesis by means of a cotton swab. A patch of lint-free gauze dabbed over the area afterwards gave a skin-like texture.

Ouelette (1969) developed a spray coloring technique. A thinned silicone-elastomer is mixed with selected pigments. The mixture is sprayed on the prosthesis until the desired hue is obtained and a catalyst spray is applied over the sprayed pigment solution.

Surface tattooing techniques have been described by Schaaf (1970). Selected pigments are mixed to the desired shade. These pigments are applied to the prosthesis with a tattooing machine. The colors are tattooed into the surface of the prosthesis until the desired shade is obtained.

The differing techniques have various disadvantages. The surface layer in the first two techniques easily peels off during manipulation of the prosthesis or during daily cleansing by the patient. In the third procedure the repeated needle puncture may weaken the structure of the prosthesis. It is difficult to tattoe the thin margins.

One has to keep in mind that a color match which is acquired artificially, usually has validity only for one light condition (this will be dealt with in chapter 3). The metameric effect caused by different illuminants will further complicate the problem of color matching. In clinical practice a mixture of average daylight from the sky, artificial daylight illuminants or a cool white fluorescent illuminant are present. This light mixture is

usually spectrally different from average daylight at noon. The prosthetic match with the skin will vary under different lighting conditions. For an isomeric color match, the spectral reflectance curves of the skin and prosthesis need to be equal. In practice this condition is difficult to achieve because of the different pigments and chemical structure of the prosthetic materials as well as of the skin.

2.4.3. The color stability of prosthetic materials

Although the use of the modern elastomers and polymers has greatly improved the facial prostheses, there is still no ideal material which resembles or duplicates human skin. The newly developed elastomers have been reviewed by Hulterström (1975), Gonzalez (1978), Lewis and Castleberry (1979) and Craig, Koran and Yu (1980).

Silastic^{R} 44210 polydimethylsiloxane was tested in an accelerated aging experiment (Craig et al., 1978). It showed an overall superiority in color stability compared with materials like polyvinylchloride and polyurethane. Ease of manipulation and processing and adequate mechanical and physical qualities make silastic^{R} 44210 the material of choice for prosthetic reconstruction.

The color change of a maxillofacial prosthesis varies with time and from individual to individual. Aging experiments with pigments have shown only minor color changes. These could not explain the degree of color change observed clinically (Craig et al., 1980). This observed clinical change may be due to staining. This staining of the prosthesis may be the result of tobaccosmoke, environmental stains, body-oils, cummulative remnants of adhesives or cosmetics applied by the patient. It is possible to remove surface staining from silastic^{R} material using 1,1,1-trichloroethane. This seems to be a promising development (Yu et al., 1981).

2.5. Summary and conclusions

The relatively small group of disfigured people, which are treated prosthetically, require the highest quality of rehabilitation. This rehabilitation is aimed at the restatement of the disfigured patient in society. The holistic medical treatment is the only one which may be effective. An adequate patient-doctor relationship, social nursery, an adequate information level of the patient and a prosthetic therapy of high quality support the patient in his process of adaptation to his handicap.

A prosthetic therapy of high quality needs an improvement of the physical and chemical characteristics of the materials and pigments. This improvement has to result in a more durable material which do not show discoloration.

The appearance of a prosthesis has to be improved by aiming at a duplication of the optical transfer of light in the skin. This means a duplication of the spectral curve of light reflected by the facial skin, an immitation of the scattering -and absorbtion coefficient. The range of colors of the facial skin has to be defined for a particular population, in order to develop a color matching system. In the future this color matching system should be extended with pigments, which are self-matching to the variations in color of the skin.

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CHAPTER 3

APPEARANCE AND MEASUREMENT OF APPEARANCE

3.1. Abstract

This chapter gives a survey of the different factors which play a role in the visual perception of objects and the different methods of measurement of appearance. The visual appearance of objects is determined by the spectral distribution of light, the interaction of light with objects, the visual perception and the different background conditions. The phenomenon of appearance is described in physical, psychological and physiological terms. Physical and psychophysical aspects of the appearance of objects can be measured with different instruments. For the psychophysical measurement the L, u*, v* color difference system (CIE, 1976) has been selected. This is one of the scales that most closely relates to the visual situation encountered.*

3.2. Introduction

The analysis of skin appearance requires an understanding of the fundamentals of color science. Appearance is the aspect of visual experience by which things are recognized. The description of appearance is obtained in terms of three factors: physical, psychological and physiological.

The interaction of these phenomena is summarized in the description of Billmeyer (1966): "The perception of the

appearance of an object mode, like the skin, is a function of the physical quality of the light, the physiological processes in the retina and brain and psychological interpretation of the physiological response".

The relation between physical stimuli and the perceptual aspects of the responses to these stimuli is encountered in psychophysics. This psychophysical concept is obtained by defined generalizations, in physical terms, of concepts derived from the subjective aspects of the response of the human organism to physical stimuli.

In this chapter the phenomenon of appearance in physical, psychological and physiological terms are described.

3.3. Physical characteristics of light

A light wave is electromagnetic energy qualitatively characterized by its wavelength, frequency or photonenergy. Photonenergy is directly proportional to frequency; both energy and frequency are inversely proportional to wavelength. A unit of measure for wavelengths is the nanometer. The energy of a photon is conveniently expressed in electron volts.

Light with wavelengths from about 400 nm up to about 700 nm gives a visual sensation. A light source may radiate over the whole of the visible spectrum. The light of a source can be plotted in terms of a spectral energy distribution curve. The Commission International de l'Eclairage (CIE) has defined standard light sources, their colors can be related to color temperatures derived from black-bodies radiating with the same color. Standard Illuminant A is a tungsten filament lamp with a color temperature of 2854° K. Standard Illuminant B is an approximation of noon sunlight with a color temperature of 4870° K. Standard Illuminants C and D 6500 each are an approximation of overcast daylight with color temperatures of 6770° K and 6500° K, respectively.

The solar spectrum is determined by the temperature of the surface of the sun, about 5700° C. The spectrum has a broad peak centered near 560 nm, a yellow-green wavelength. The eyes are most sensitive to specifically this wavelength region. Roughly speaking, light is perceived as being white if its spectrum resembles that of sunlight (Fig. 3.1).

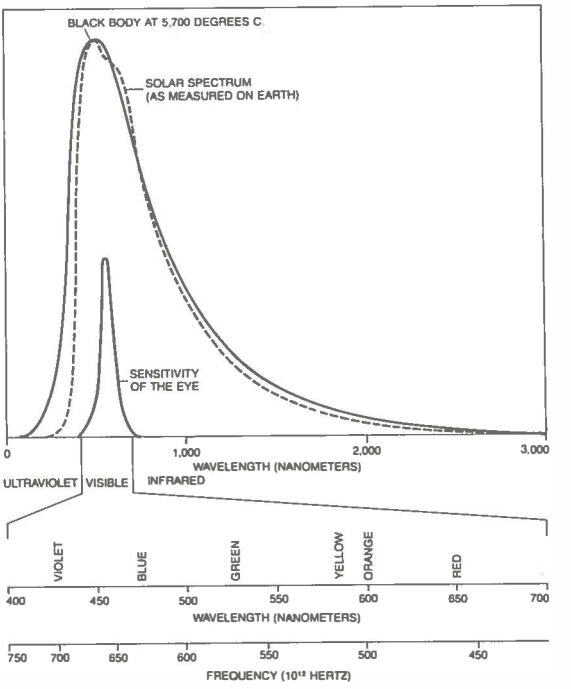

Figure 3.1
The sensitivity of the eye closely matches the spectrum of sunlight. The sun's radiation is approximately that of a black body with a temperature of 5700° C. The spectrum can be described in units of radiant power per area as a function of wavelength or frequency (or energy) (adapted from: Scientific American, Oct., 1980).

The quantity of light is defined as the radiant flux (= energy per unit time) emitted, transferred or received through a surface (watt/m^2).

3.4. The visual sensation and perception

The *sensation* can be defined as the uninterpreted conscious caused by the stimulation of a sense receptor, whereas the *perception* can be defined as the combination of different sensations and the utilization of past experience in recognizing the objects from which the stimuli come (Hunter, 1975). The visual sense enables us to perceive, among other things, the color of lights and objects. The eyes are a detector of light, are sensitive to the direction of light, to different amounts of light and to the quality or wavelengths of the light.

The perception of color is related to the wavelengths present in the stimulus. However the eye is not equally sensitive to light of all wavelengths. Research in the effectiveness of the radiation in stimulating the eye (and producing a visual sensation) resulted in the definition of the spectral luminous efficiency curves for photopic vision and scotopic vision which were adopted by the CIE respectively in 1924 and 1951.

Color vision is subserved by photoreceptors. Marks and Dobelle et al. (1964) provided the final proof for the existence of three photoreceptors, the cones, with different spectral sensitivities: one primarily red sensitive, another primarily green sensitive and the third primarily blue sensitive. The best estimates of their spectral sensitivity functions are derived by Vos and Walraven (1978). The currently accepted theory of color perception zone was already proposed by a.o. Müller (1930). According to this theory the responses of these three types of color receptors in the retina are converted in the eye and optic nerve to opponent-

color signals, as first postulated by Hering (1878). This theory states that there are six primary color sensations which are subserved by three opponent color systems: black-white, red-green and yellow-blue. For a review of modern zone theories of color vision see Bouman and Walraven (1972).

The perception of light in relation to its physical parameters is called the science of psychophysics. The law of Fechner defines the approximately logarithmic relationship between physical luminance of the light source and perceived lightness. A power law (with exponent 1/3) may even provide a better description (Stevens, 1953). In actual practice the surroundings and the adaptation modify this relationship (e.g. Stevens and Stevens, 1963). The visual mechanism is capable of evaluating very small color differences, but this too depends on the observation conditions. Although the eye cannot make exact quantitative measurements, it can be used as a very sensitive discriminating sensor in a matching situation.

3.5. The modes of appearance-psychological component

In a phenomenological approach Katz (1935) was among the first to describe the complex ways in which colors are perceptually experienced. The classification of Katz was adopted (although simplified) by the Committee on Colorimetry of the American Optical Society (1953). In particular the difference between self luminous (aperture mode) and reflected color (object mode) is important.

As for the prosthesis and the skin the object mode of appearance has to be applied. The relevant attributes of this mode as perceived by an observer are: lightness, hue, saturation, texture, transparency, duration, size, shape, location. Lightness, hue and saturation form the three different dimensions of color perception proper.

In addition to the above attributes it is necessary to know the existence of psychological primary colors (Hering, 1878; Wyszecki, 1953) such as red, yellow, green, blue, black and white.

The approaches and findings of psychology are applied to vision by Arnheim as cited by Hallarman (1971). In this concept, vision is a creative activity of the mind. Accordingly the response to the phenomenon of vision is strongly influenced by environmental experience and cultural patterns.

3.6. Physiological effects influencing color perception

The color of an object as perceived in the every day experience is intricately related to the perceptions of the environment under study and the various physiological responses of the eye. This visual response varies with the physical parameters of both the stimulus and those of the other stimuli in the field of view. This finds its expression in a number of visual phenomena to be discussed.

3.6.1. Simultaneous brightness contrast

This refers to the changes in the lightness or brightness of a stimulus due to the presence of a neighbouring stimulus. This causes an instantaneous adjustment of the visual system and produces dramatic effects in brightness perception. The result of several investigations indicate that the magnitude of the contrast effect decreases rapidly with spatial separation (e.g. Leibowitz, Mote and Thurlow, 1953; Beck, 1972; Walraven, 1973).

3.6.2. Simultaneous hue contrast

The hue of a visual stimulus changes when a background of a particular hue is introduced. The stimulus takes on the complementary hue. Kinney (1962) reported that the

amount of the complementary color induced in a central testfield increases as the size of the inducing background field is increased and as the luminance ratio between testfield and inducing field is increased. For a review of the phenomenon of color contrast see Walraven (1981).

3.6.3. Effects of texture, contour and configurational factors

Texture is the quality of the structure of a surface. The perceived contrast may be reduced in the case of textured stimuli (Woodworth and Schlossberg, 1955). Contrast may be greater with a sharp contour than with a graded contour (O'Brien, 1958).

Benary (1924) and Coren (1969) reported the importance of figure-ground relationship i.e. different contrast effects depending on which part of the pattern is seen as figure and which is belonging to the background.

The perceived contrast is reduced if the stimulus in question is seen as separated from the background (Mershon and Gogel, 1970). *Summarizing:* several experiments have shown that subjective contrast is a function of the luminance size, degree of texture, contour, figure-ground relation and separation from the background. Additional concepts are needed to fully explain this subjective contrast (Berman et al., 1965).

3.6.4. Assimilation

Evans (1948) illustrated the opposite effect of contrast. Colored areas appear lighter when overlaid with white lines than overlaid with black lines. This phenomenon is called assimilation. Helson (1964) hypothesized that small differences in stimulation in neighbouring areas result in summation of retinal responses: yielding assimilation. However, large differences result in inhibition.

3.6.5. Adaptation and color constancy

Light and dark adaptation refer to the changes in sensitivity which allows the eyes to adjust to changes in illumination. In color perception only photopic stimulation is relevant. Adaptation to colored lights causes differential adaptation in the three types of cones. This effect is responsible for color constancy, that is, the fact that objects may retain their "normal" color although the physical stimulus may vary due to spectral differences in the illumination. This leads to the idea that color is the property of the surface of an object. Theoretical explanations date already from Helmholtz and Hering but the mechanisms involved are still but partly understood as reviewed by Walraven (1981).

It is possible to judge the shapes of objects by our visual impressions of them and to compare these with factual experiences involving similar objects. However such associations in the situation of color are manifestly impossible.

3.7. The relation of the physical stimulus and the psychological sensation

Although the perception of the object mode of appearance is an extremely complicated situation, described in chapter 3.6, there is a physically measurable property of an object that is related to its perceived color i.e. the light reflected by the surface of the object. To satisfy a practical need in engineering applications one may postulate a causal relationship between the incident physical stimulus and the perceived color.

This psychophysical domain is essentially artificial (Wright, 1969) and obtained by defined generalizations, which will be explained briefly in the following chapters.

3.7.1. The system of color specification

The system of specification of color is based on the 1931 CIE standard observer (Wyszecki and Stiles, 1967). This is a hypothetical average observer described by the CIE spectral tristimulus functions ($\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$) recommended in 1931 for a 2^{o} field of vision. A supplementary observer for a larger 10^{o} field was adopted in 1964. Both were formulated as a result of color matching experiments in the aperture mode.

CIE colorimetric tristimulus values (X, Y, Z) are obtained from the integration of the $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ functions multiplied by the spectral distribution of the color stimulus. These CIE tristimulus values are obtained from spectrophotometric data. The tristimulus values for an object color are calculated by the multiplication of the spectral energy of the light source times the spectral reflectance of the object times the tristimulus functions of the observer, expressed in the coordinate system for object colors CIE (Y, x, y) (Fig. 3.2.).

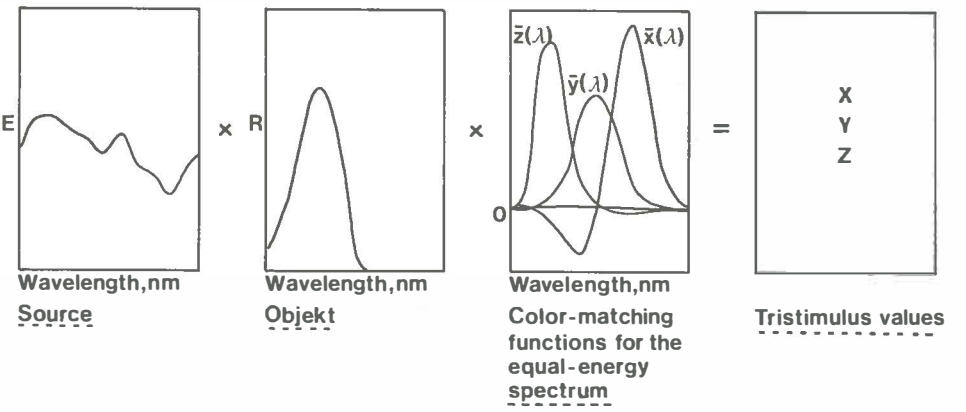

Figure 3.2

The tristimulus values for an object color (Y, x, y) are calculated from the spectral reflectance of the object, times the spectral energy of the lightsource times the tristimulus functions of the observer,

$$x=\frac{X}{X+Y+Z};\quad y=\frac{Y}{X+Y+Z}$$

Later on transformations of this colorimetric coordinate system were proposed to achieve that visual color differences correspond uniformly to coordinate differences. This modification was based on visual discrimination and magnitude scaling experiments and resulted in the development of uniform color scales.

The various characteristics of the uniform color spaces are:

1. The color spaces yield approximately uniform relationships of perceptual color differences to numerical differences in coordinates of the space.
2. The dimensions of the spaces are more or less relatable to visually recognized attributes of color appearance.
3. There is a non-linear relation between object luminance and the lightness dimension, similar to the non-linear receptor response found in electrophysiological experiments (a.o. Boynton and Witten, 1970).

Within this framework, there are a variety of numerical scales used to express color difference (Hunter, 1975). They all have the specific advantages and disadvantages and have specific applications (Boynton, 1979).

Hunter (1975) criticizes in this aspect: "neither the numerical measurements of color difference nor the relationships of these measurements to visually observed color differences can be considered to be well standardized or reproducible from one experimental setup to another".

Various units are used to quantify color differences. They are related to different spaces. The spaces (systems) are described by Hunter (1975) and can be traced to one of the three following psychophysical systems.

1. The Nickerson Index and the Adams-Nickerson unit, based on Munsell scales of hue, value and chroma. These are three variables in an experimental system of paper chips with perceptually uniform color differences.

2. The N.B.S. unit of Color Difference (Judd-Hunter N.B.S. Unit), based on the threshold between commercially acceptable and unacceptable color matches.
3. The Mac Adam Unit, representing the minimum perceptable color difference determined by Mac Adams experiments (1942, 1943).

The relationships between the three color difference units are that 1 NBS unit is about equal to 2 or 3 Mac Adam units whereas the Munsell Value unit is about 10 to 30 times the size of the Mac Adam unit.

3.7.2. Recommendation for the selection of color scales

One single international recommendation for a color space is not available. The CIE recommends the use of two approximately uniform color spaces and associated color difference formulae (CIE, 1976).

1. The L*, u*, v* space which is a slightly modified version of the CIE 1964 color difference formula, which is based on a projective transformation of the x, y chromaticity diagram (for constant lightness L*).
2. The L*, a*, b* space, which is a cube root version of the Adams-Nickerson color-difference formula, in which straight lines in the (x, y) chromaticity diagram become curved lines.

Preference for one or the other formula would be based mainly on convenience of use in particular industrial applications (CIE, 1976). The L function defining the lightness correlate in the CIE 1976 (L*, u*, v*) space is identical to the L* function of the CIE 1976 (L*, a*, b*) space. No simple relation exists between the scales u*, v* of the (L*, u*, v*) space and a*, b* of the (L*, a*, b*) space.

3.7.3. The selected color scale

In this research project the specimen class can be described as diffusely reflecting objects.

As a result we selected a color scale based on the N.B.S. unit of color difference the L*, u*, v* color space (Fig. 3.3.).

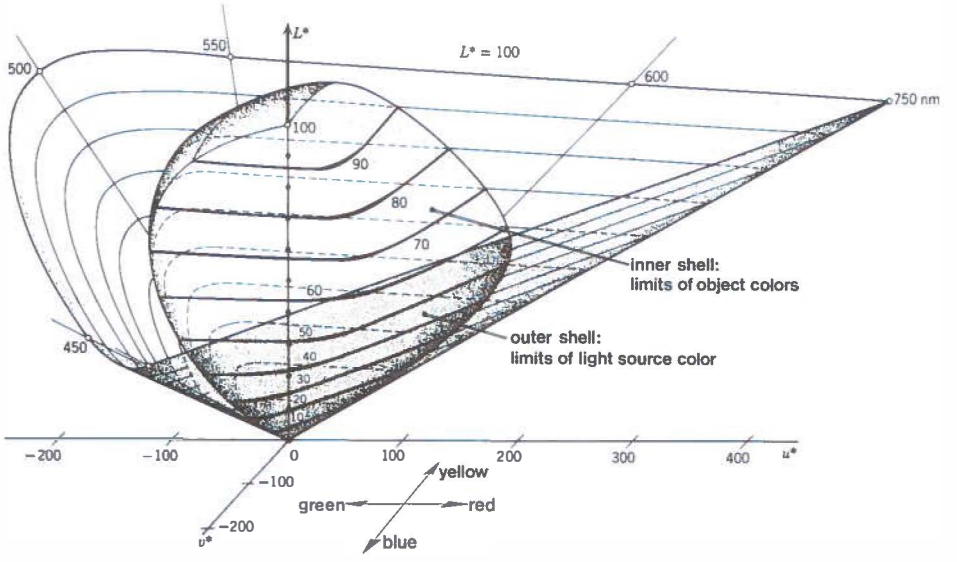

Figure 3.3.
Sketch of (L, u*, v*) object-color space with respect to CIE standard illuminant D_{65} and the CIE 1964 supplementary standard observer. The colors of all object-color stimuli fall within this boundary.*
(From: D.B. Judd and G. Wyszecki: Color in Business, Science and Industry, 1975, published with permission of J. Wiley & Sons, New York).

This represents an estimate of magnitude of commercially acceptable color difference with 100 units falling between black and white. This unit is used in an opponent color

model with rectangular coordinates for chromaticity. The scale is approximately uniform in the relationship of visual intervals to numerical differences in lightness and chromaticity.

The difference between two colors (CIELUV) is defined as $\Delta E^*_{uv} = (\Delta L^{*2} + \Delta u^{*2} + \Delta v^{*2})^{\frac{1}{2}}$ (CIE, 1976).

3.7.4. The requirements to observations

The final stage in the observing situation is the human observer. The most effective conditions for making visual evaluations are based on studies concerning the capabilities and insufficiencies of the eye and the brain (Boynton, 1979).

Standardized conditions must be applied in order that such evaluations are reproducible i.e. the light source (intensity, angular size and spectral distribution), the observation geometry and the environmental conditions.

In 1971 the CIE recommended the colorimetric specification of opaque specimens, corresponding to one of the following conditions:

1. The specimen is illuminated by one or more beams whose axes are at an angle of $45^\circ \pm 5^\circ$ from the normal to the specimen surface and viewed with an angle not exceeding 10° to the normal (45°/normal).
2. The same as in 1 but reverse: normal/45°.
3. Diffuse/normal, the specimen is illuminated diffusely by an integrated sphere. The angle between the normal to the specimen and the axis of the viewing beam should not exceed 10°.
4. The same as in 3 but reverse. Normal/diffuse, the angle between the axis and any ray of the illuminating beam should not exceed 5°.

For the latter two conditions the specification of a gloss trap in size, shape and position should be given (Wyszecki, 1978).

3.7.5. Metamerism

Metamerism is the effect that two objects with spectrally different radiations produce the same color under the same viewing conditions (CIE, 1972). Wyszecki and Stiles (1967) define metameric colors as color stimuli of identical tristimulus values but different spectral energy distributions. In addition to this, the problem is more complex because a color in a matching situation may be metameric for one observer but not for another observer. Colors of identical spectral energy distributions ($P_{1\lambda} = P_{2\lambda}$ for all λ) are called isomeric colors.

A measure of the degree of metamerism under a given illuminant is recommended by the CIE (1972), which is the index of color difference, ΔE, between the two specimens computed for the given illuminant when tristimulus identity exists for the reference illuminant (CIE standard illuminant C). In other words: there is no metamerism under illuminant A when the color difference ΔE between a pair of colors that match under illuminant C is zero under illuminant A.

In most practical situations an exact metameric match is rarely if ever accomplished. Degrees of metamerism of greater than 2 or 3 indicate that the mismatch between the original and the reproduction may be objectionable large under those illuminants (Judd and Wyszecki, 1975).

In the situation of a color match between a facial prosthesis and the skin, the colorant formulation of the reproduction of the skin should be such that an isomeric match is obtained. Rodriques and Besnoy (1980) concluded that there is little agreement about the desirable approximation to isomerism between scientists and industrial colorists. The main areas of agreement are: "The spectral curves of metamers must have at least three crossovers, one in each area of maximum response of cones" and "Any color match is metameric if its pigmentation differs from that of the standard". The Inter-Society Color Council Committee on

Indices of Metamerism collects all observations, with the goal of resolving the technical questions of an ideal color match.

3.8. The geometric attribute of object appearance

Whereas color is an attribute of object appearance, that can be assessed under different conditions of illumination, there are other attributes of object appearance such as gloss (for opaque objects) or haze (for transparant objects). These attributes are very dependent of the spatial distribution of the incident light. We call these geometrical attributes of appearance. Gloss, for instance is an attribute of surfaces that causes them to have a shiny or lustrous appearance. Our perception of geometric attributes does not have the tridimensional limitation of our color perception. It is not possible to produce an equivalent gloss stimulus synthetically. To formulate a geometric scale of gloss, a number of specimens are ranked visually and correlated with measurements under different conditions. A variety of geometric scales has evolved, each to meet unique application requirements (Hunter, 1975).
In this project we have not measured the geometric attributes of the skin surface.

3.9. The identification of chromatic and geometric appearance

The methods to quantify appearance may be separated into three different kinds i.e. visual color or gloss identification, psychophysical evaluation and physical measurement of color and gloss.

3.9.1. The visual identification of color

Several methods to visually identify colors by means of comparing them to a standard set of colors have been developed (Hunter, 1975). For some of these methods the colors of the standard comparison set have been expressed in terms of the CIE system of color specification (see 3.7.1.). Two of these methods are discussed in this chapter.

3.9.1.1. Color identification by collections of colored chips.

A number of different systems are used for the arrangement and identification of the chips of these collections. Only the Munsell system is discussed in this chapter. The system has five primary hues: red, yellow, green, blue and purple and five intermediate hues. All these ten hues are subdivided according to value (lightness) and chroma (saturation). The 3 quantities form the three dimensions of the system.

The Munsell chips do not include all the theoretically conceivable colors. A complete designation of color in Munsell terms is given as hue/value/chroma. Sproull (1973) described this system in the dental literature.
Munsell color designations are achieved by visual comparisons in a disk colorimeter or by visual comparison alone. Nickerson (1969) has documented the historical development of the Munsell system and designated all chips with colorimetric specifications by X, Y, Z values for a specified illuminant. The evaluations by the eye are subjective, variable with changes in viewing conditions and variable from observer to observer.

3.9.1.2. Color identification by a subtractive color mixture.

Subtractive colorimeters provide a comparison field whose color is controlled by introducing three filters into a single beam illuminating the field. The luminance of the comparison field can be controlled independently. Each of the three filters subtracts a certain fraction of each part of the spectrum. The Lovibond-tintometer is such an instrument.

Subtractive combination of one unit of each of the red, yellow and blue scales results in a filter perceived as nearly neutral. The calibrations of the Lovibond glasses are carried out by the maker with such precision that any errors remaining cannot be detected by an observer (Judd, 1975).

Conversion graphs have been prepared from which the CIE specification (Y, x, y) can be obtained easily. Haupt et al. (1972) have converted the data of the Lovibond color system to three colorimetric coordinate systems: the CIE 1930 (x, y) diagram, the CIE 1960 (u, v) diagram and the CIE 1964 (U^*, V^*, W^*) system for both CIE standard illuminant A and C. All these data correspond to the 2^o field of vision.

3.9.2. Instrumental identification of color

The color measuring instruments are used because of their marked ability to measure and record in a quantitative way. These instruments differ from each other mainly in the type of evaluation device and the method of spectral selection. Two major classes of instruments are: tristimulus colorimeters and spectrophotometers.

3.9.2.1. Tristimulus colorimetric instruments

The principle of this type of photoelectric instrument has three photocells with spectral sensitivity curves that are linear combinations of the spectral tristimulus func-

tions of the CIE standard observer ($\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$) respectively. The photocurrents are then proportional to the CIE tristimulus values X, Y, Z. By comparison of the photocurrents measured from the sample with those measured from a standard white sample, both samples illuminated with a CIE standard light source (often C or D 6500), conversion in the CIE (Y, x, y) coordinate system for object colors can be achieved.

Many instruments have been developed in the past (Billmeyer, et al., 1966; Hunter, 1976). However, according to the view of Billmeyer (1966) a common and serious defect of colorimeters is the fact that with existing sources, filters and detectors it is very difficult to make the spectral characteristics of different colorimeters exactly alike. For this reason readings of tristimulus colorimeters should never be considered to have any absolute significance. The accuracy of different colorimeters referenced to a General Electric spectrophotometer was determined by Billmeyer (1974). He showed color differences with a mean of 2.6 Mac Adam units (FMC-2).

Nevertheless tristimulus instruments provide a cheap and sensitive method for detecting and measuring small differences in color. This differential measurement is highly reproducible from one properly adjusted colorimeter to another (Billmeyer, 1962). Calibration for a color near the color of interest is needed.

3.9.2.2. Spectrophotometric instrument (physical evaluation)

In contrast to a colorimeter a spectrophotometer measures the reflectance or transmittance factors at many wavelengths referenced to a standard. The output of such an instrument is a spectral reflectance or transmittance curve. From these curves combined with the spectral energy distribution of a (standard) illuminant, the color, expressed in Y, x, y or L^*, u^*, v^* can be computed.

The spectral information can be used for color appearance analysis, recipes for color reproduction, chemical analysis and ingredient identification.

The selectivity of wavelength isolation varies considerably among spectrophotometers. The most selective instruments are used in chemical analysis. For color measurement sometimes an abridged spectrophotometer is used, in which spectra transmittance or reflectance is determined for a selected set of discrete wavelengths.

Spectrophotometry is the only practical way to obtain tristimulus values which are not dependent on calibrated color standards and show no metamerism. The accuracy of different spectrophotometers compared with the General Electric Spectrophotometer has been determined by Billmeyer (1974) and resulted in the same order of standard error as the accuracy of tristimulus colorimeters.

3.9.3. Instruments for the geometric attribute of object appearance

The instruments measure the attributes associated with the capacities of surfaces to remit incident light in different directions. Several types of instruments are used for measuring these geometric attributes, two of them will be mentioned here.

- *Goniophotometers* measure the amounts of light reflected or transmitted at all angles at specific directions of incidence. They provide physical data related to the object properties responsible for geometric attributes. Goniophotometers are also used to select the best fixed-angle conditions for measurement of gloss, texture, luster, transparency, haze and other simple geometric appearance attributes of specimens.
- *Specular glossmeters* measure specular surface reflection. The specular angle of view is always opposite to the angle of incidence. The specifications for any gloss measurement must involve the specular angles and field

analyses, for example called for by the 60° method of ASTM D523. This specification is used for the classification of paints or plastics (Hunter, 1975). It is often difficult to instrumentally measure object properties, that predict its geometrical attributes of appearance, especially if the resulting light distributions on a surface has such fine spatial structure that a high resolving power of reflectance measuring instruments is required. Also perception of geometric attributes is multivariate and not tridimensional as color perception is. Modern glossmeters are abridged applicable only.

3.9.4. Reflection standards and standardization

Standards provide the permanent bases against which appearance attributes are measured. The accuracy and precision of measurement depend directly upon the accuracy and precision of the standards being used and on the condition and cleanness of these standards (Hunter, 1975; Carter, Billmeyer, 1979).

The standards are classed as primary-standard, transfer-standard and working-standard.

A primary standard is a standard to which a value is assigned by an agreed convention. Such a standard may be a theoretical concept only, not realizable in practice.

A primary standard of reflectance factor (CIE) is the perfect reflecting diffuser which reflects 100% of the incident light on it in such a way, that the luminance of the diffuser is the same in all directions in which the light is reflected.

A transfer standard is a material standard which has been calibrated by a recognizing standardizing laboratory in terms of an accepted primary standard. It can be used to "transfer" a calibration from one instrument to another. Two of the many suitable materials for transfer standards referred to in reflection measurements are the barium sulfate tablet for diffuse measurements (ASTM method E-306)

and the polished black glass mirror for specular instruments (ASTM method D-2457).

A working standard is used with a particular instrument only, for use in maintaining the calibration of the instrument.

Other factors affecting the validity of color data are instrument-related such as accuracy and stability of the photometric scale, wavelength scale or the filter properties (Robertson, 1965). Also the sample has to be stable over a period of measurement. The precision of one instrument over a period of time is also a factor of concern. This was investigated by Billmeyer (1974) and Heinrich (1976). Short term instability within some days produced a mean color difference of 0.2-0.4 Mac Adam units (FMC-2). Long term instability was investigated by Luckacz (1973) and Heinrich (1976). Their investigations over two till six months showed that the stability of a spectrophotometer (Hardy) as well as a tristimulus colorimeter did not exceed a standard error of 0.2 in X, Y, Z.

3.10. Selection of the method

It is a familiar fact that our eyes are sensitive to very small differences in the intensities of lights over an enormous range of intensities. However, the memory ability of the eye-brain organ is limited. A measurement instrument may be considered to be an expedient for the eye-brain organ. For the determination of the color difference of two objects or of one object at two successive events, we have chosen out of two types of instruments, the spectrophotometer and the colorimeter. The spectrophotometer determines the physical measurement of the distribution of light of an object (3.9.2.2.). The colorimeter determines the psychophysical analysis, which simulates the operation of the eye and brain in judgements of appearance (3.9.2.1.). This

latter method provides a cheaper and sensitive method and particular instruments are equipped with fibre optics. We selected two colorimetric instruments: the Lovibond Tintometer MK III and the Photovoltmeter. Both instruments were tested. The photovoltmeter was unsuitable because of instable color filters. The Lovibond system permits the application of the color difference measurement on the skin of the facial area. The measuring head is small enough to prevent bulging of the skin into the measuring head. This bulging may disturb the standardized conditions (3.7.4.).

The preferred and adapted method is to be described in chapter 5. The Lovibond subtractive colorimeter has the limitations of being applicable in measurements of color difference only. The error of measurement of the instrument and the observer has to be verified.

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CHAPTER 4

THE APPEARANCE OF THE FACIAL SKIN

4.1. Abstract

The appearance of the human skin is determined largely by the transfer of optical radiation. The human skin is a complex, dynamic and multilayered organ. Within any of the layers of the skin the incident radiation, if not returned by specular reflection, is absorbed or scattered. There are specific chromophores viz. melanin, hemoglobin, carotene and bilirubin. Melanin is confined to the epidermis, whereas carotene is present in the stratum corneum and fat layer. The two forms of hemoglobin are confined to bloodvessels in the dermis, and bilirubin is situated in the dermis as well.

The concentration and distribution of the chromophores determines the absorption coefficient. The concentration of melanin and hemoglobin may change rapidly, which causes changes in the absorption coefficient. Scattering is of major importance in the dermis. This largely influences the depth of optical penetration. The variation in the appearance of the skin is influenced by anatomical, photobiological, physiological and hormonal factors.

A continuous color match between the complex, variable medium of the skin and a prosthesis is probably not attainable. Self-adapting color matching is not available yet. Therefore prosthetic material should possess an absorption coefficient and a scattering coefficient. The material should have the same spectrophotometric curve as those of

the skin. This will result in an optimal color match between a facial prosthesis and the skin at one moment of time only.

4.2. Introduction

The appearance of an object is defined as the aspect of visual experience by which things are recognized (Hunter, 1975). This visual identification of appearance can be divided into color properties and geometrical properties. The geometrical properties can be summarized as gloss, turbidity and texture.

The appearance of a human skin, especially the color properties, has a continuously varying character. Description of it is possible, by considering the appearance of the skin from two aspects (Quevedo, 1974). One aspect is the constitutive appearance, the second the facultative appearance. The latter consists of the complex interplay of the external factor light and internal factors such as hormones and other physiological processes. A brief description of its morphology is required to understand the optical radiation transfer in the skin and the consequences for its appearance.

4.3. The constitutive morphology of the skin

The skin is composed of two layers of distinctive structure, properties and embryologic origin (Gray, 1980). The outer layer, epidermis, is an epithelial layer which covers the dermis. The dermis is a connective tissue layer of mesenchymal origin. Underneath the dermis lies a layer of loose irregular connective tissue, the superficial fascia which in turn is bound to the underlying tissues by a dense fibrous deep fascia (Fig. 4.1.).

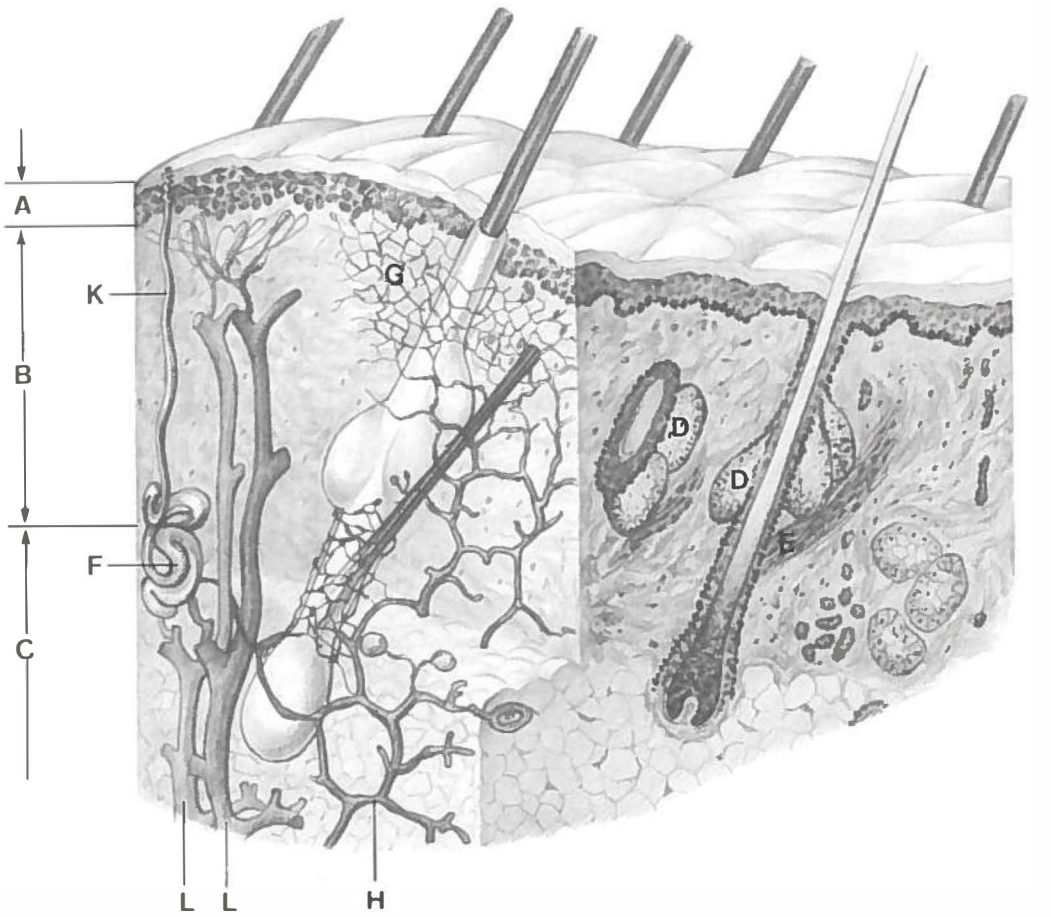

Figure 4.1
A diagrammatic scheme showing the structure of the skin. A = epidermis; B = dermis; C = cutaneous fat; D = sebaceous glands in association with a hair follicle; E = arrector pili muscle; F = sweat glands; G = superficial nerve plexus; H = deep nerve plexus; K = duct of sweat gland; L = cutaneous vessels. (Adapted from Gray's Anatomy, 1970).

To understand the penetration of light in the skin a description of the anatomy of the various skin layers is required.

4.3.1. The surface of the skin

The surface of the epidermis is characterized by various furrows, ridges, endings of the hairfollicles and sebaceous- and sweat glands. The skin has a network of linear furrows, the tension lines. The lines divide the surface in a large number of polygonal areas. They correspond with the collagenous bundles of the reticular layer in the dermis (Gray, 1980; Zelickson, 1967). On the palmer surface of the hands and the soles of the feet papillary ridges are visible. All of the other surface markings are individually different. The precise positions are related to the arrangement and size of underlying dermal papillae (Zelickson, 1967). The profilometry of the skin has been reviewed by Cook (1980).

The thickness of the skin varies from one body region to another. Most of this variation is accounted for by differences in the thickness of the dermis. The epidermis is relatively uniform in thickness except in the palms and the soles (Ebling, 1979).

4.3.2. The anatomy of the skin

The epidermis is a stratified squamous epithelium. It is composed of tightly packed cells, called keratinocytes. These cells continually migrate from the basal layer toward the surface. In this process they flatten and form several separate layers.

The outer layer is the stratum corneum which is composed of ten to twenty single-cell layers of densely packed flattened dead keratinocytes. This layer is rich in keratoprotein and contains in addition lipids, melanin granules and carotene. It has a thickness of 8-15 μm. Beneath the stratum corneum is the stratum granulosum, which is composed of two to four cell layers with a total thickness of 3 μm.

In these cells keratohyalin granules are formed, averaging 100 to 200 nm. Below this layer is the stratum Malpighii, which is composed of ten to twenty layers of keratinocytes, with a thickness of 50-150 µm.

The basal layer of the epidermis is a single cell layer of columnar basal cells which divide, to produce the keratinocytes of the stratum Malpighii. Melanocytes are also present in this layer, producing melanin granules which are transferred into the keratinocytes. This layer has a typical thickness of 5-10 µm (Zelickson, 1967; Parrish et al., 1978). Thus the total thickness of the epidermis amounts to 100-200 µm.

The ultra structural dimensions of most of the important cellular constituents of the epidermis ranges from 7 nm for the filaments of keratin up to 7 µm x 2 µm for the mitochondriae (Zelickson, 1967). In the basal cell, melanin can be seen, frequently in the form of melanosome complexes, which are limited by a membrane and contain a finely particulated matrix. The melanin particles appear as dense ovoid-shaped bodies, the length of which varies from 0.4 to 1.0 µm and the width from 0.1 to 0.5 µm. In the stratum granulosum and stratum corneum the melanosomes are rarely seen. Only in heavily pigmented white skin and negro skin melanin is present within the stratum Malpighii, stratum granulosum and sometimes even the stratum corneum.

The *dermis* is a layer of fibrous connective tissue. It consists of a thin superficial, papillary layer and a thick deep reticular layer with a total thickness of 1-4 mm (Parrish, 1979). The papillary layer is composed of widely separated, collagenous bundels, reticulum and elastin fibers and of a capillary network. The reticular layer is composed of strong branching collagenous fibre bundels. Most of them are oriented parallel to the surface, with only some perpendicular to it. The wide intervals are occupied by adipose tissue and sweat glands (Gray, 1980). The diameter of the collagen and elastin fibers range from

15-140 nm with a length of 1 to 15 µm. In the adult dermis several hundreds of these collagen fibers are tightly bound together in the collagenous fiber bundels. The fibers are embedded in a ground substance of water (bound to hyaluronic acid) and mucopolysaccharides (Zelickson, 1967). The hyaluronic acid molecule has a cubal form with a length of 0.3 nm. The cappilaries and arterio-venous anastomoses in the papillary layer have a diameter of 15 µm. They have generally no muscle coat (Ryan, 1973).

The interface between the epidermis and dermis is marked by ridge-groove interdigitations. Epidermal cones and ridges of different sizes, project into the dermis enclosing between them highly vascular dermal papillae. The regional differences in the architecture of the epidermal ridges and papillae are related to the arrangement of hairs and glands (Gray, 1980).

Below the dermis is situated the subcutaneous fat with the lipophilic chromophore β-carotene concentrated in it. This chromophore is sometimes also found in the stratum corneum (Edwards, Finkelstein, 1951).

4.3.3. The blood vessels of the skin

The arteries from the deep plexus enter, through the subcutaneous adipose tissue, the deeper layer of the dermis. An artery of about 100 µm in diameter has a lining of endothelial cells which lie on a relatively thick elastic membrane. The arteries divide once or twice as they pass through the lower dermis and their branches run vertically until they reach the mid-dermis where they divide again. In the mid-dermis they are about 50 µm in diameter. The repeated subdivision of the arteries in arterioles and capillaries reduce the diameters of the vessels to 15 µm by the time they reach the upper dermis. Further branching of the vessels gives rise to a network of horizontal capillaries lying parallel to the surface in which sometimes a superficial and a deep horizontal sub-papillary plexus

can be recognized (Ryan, 1973).

Above the sub-papillary plexus are the terminal capillaries (vertical loop) which supply the papillae of the dermal-epidermal junction. These terminal capillaries drain into the horizontal sub-papillary venous plexus.

The number of capillaries supplying the skin has been counted by many authors (Ryan, 1973). It is noted that there are great interpersonal and inter-regional differences. The regional differences in density of capillary loops per sq. mm of skin surface vary for the outerside of the forearm (42 per mm^2) and for the face (150 capillary loops per mm^2).

The thickness of the epidermis may vary due to change in the vascular pattern. This interaction is described as the Hautangion or epidermal capillary unit.
Consequently: the contribution of the number of capillaries and the thickness of the epithelium to the facial skin color is important.

4.3.4. The innervation of the skin

The skin is richly innervated by fibers of the cerebro-spinal and anatomic nerves and via non-myelinated efferent anatomic fibers supplying blood vessels, sweat glands and smooth muscle fibers associated with the hairs.

4.4. The facultative morphology of the skin

The skin appearance may change due to photobiological, physiological and hormonal influences. The facial skin color is influenced by photobiological and physiological factors and may change due to inflammation reaction and by ageing of the skin. These effects will be described and summarized in Table 4.1.

4.4.1. Photobiological factor

The electromagnetic spectrum with wavelength of 290-400 nm of terrestrial sunlight, striking the human skin, may cause a reaction of the skin. The biological effects of UV radiation result from a complex sequence of biochemical reactions and cellular responses. Some may be distant from the site of absorption. The skin's response to UV exposure is characterized by changes in bloodflow, changes in cell kinetics and pigment production, and is in general a reparative and protective reaction. This reaction is characterized by an immediate and delayed erythema and an immediate and delayed tanning.

Erythema consists of vasodilatation and increased quantities of blood in the dermis, and can be caused by direct or indirect factors (Johnson and Daniëls, 1969). Synthesis of melanin starts immediately by darkening of the bleached melanin or between 2 and 19 days after exposure of wavelengths of 290-320 nm. The threshold dose of UV-light varies considerably from one subject to another and lies somewhere around 1.0 mJ/mm^2 for monochromatic 300 nm light (Magnus, 1976).

Melanogenesis is under complex genetic hormonal control, and is influenced by other physiological and pathological factors (Riley, 1974). On comparing one skin site with another in persons of different race, no statistically significant differences in the number of epidermal melanocytes was found by Fitzpatrick and coworkers (1979). Differences in the amount of melanin depend mostly on the secretory activity and the size and distribution pattern of the melanocytes. The melanoblasts are most numerous in the skin of the head and the neck where about 2000-4000 per mm^2 of surface epidermis have been found. The lowest population density has been found in the skin of the thigh and the arm, about 1000 per mm^2 on an average (Szabo, 1954; Bleehen et al., 1979).

Table 4.1. Relation between causal factors and skin response, which result in a change of appearance of the skin.

internal-external factors ↓	skin response →	epidermis		arterio-venous plexus		fluid
		epithelial thickness	melanin pigment	hemoglobin O_2-dissociation	vasculature	content of the dermis
UV irradiation		+	++		++	
temperature				+	++	
hormonal			+		+	
emotional					++	
mechanical					++	+
inflammation					++	+
ageing		+			(+)	

Increased pigmentation can also be due to endocrine causes such as occur in pregnancy, melasma and Addison's disease (Bleehen and Ebling, 1979).

4.4.2. Physiological influences on skin color

Man can only tolerate a variation of about 4° C in his own deep body temperature without impairment of physical and mental work capacity. Thermoregulation is necessary to protect the body tissues against overheating and cooling. The body attempts to maintain a temperature equilibrium by metabolic heatproduction, radiant heat exchange, convective heat exchange and evaporative heat loss. A storage in the fat layer and fluid retention is present in the body, if the body temperature varies (Åstrand, 1977).

The blood as a transport mechanism of the produced energy is cooled or insulated at the peripheries of the capillary loops by the arterio-venous shunts (Ryan, 1973). In a hot environment the setpoint of the temperature regulating center in the hypothalamus is lowered and the subject experiences a vasodilatation in the skin and perhaps activa-

tion of the sweat glands (Åstrand, 1977). During cold weather the setpoint becomes elevated and a local vasoconstriction and a drop in skin temperature reduce radiation and convection (Åstrand, 1977).

Sweating and dilatation of skin blood vessels may not occur simultaneously. Sweat production may cause a vasodilatation, alternatively at high evaporative sweat rates the skin may cool, resulting in vasoconstriction and reduced blood flow (Åstrand, 1977).

Two distinct kinds of thermoreceptors have been identified in hairy and glabrous skin of man. Such receptors show a steady discharge dependent on temperature. Each different fiber is connected with a few receptive spots with a diameter in hairy skin of less than 1 mm (Iggo et al., 1975). Cold receptors are active if the skin temperature is lower than about 30° C. Heat receptors are active above 40° C. In between 30°-40° C both receptors are active. These sympathetic fibers determine both the degree of vasodilatation or the degree of vasoconstriction of arterioles and veins.

The color of the skin, in addition to the thermoregulatory system and sympathetic arteriolar control mechanism is affected by numerous other factors, for example: cooling of the skin and localized erythematous eruptions.

Cooling the skin, noise, cutaneous pains, chemical or mechanical stimulation of internal organs, forced deep inspiration or expiration and inhalation of tobacco smoke or carbon dioxide, for example, cause vasoconstriction of the vessels of the skin (Ryan, 1973). The adrenal medullae potentiate the neural peripheral vascular reflexes at times of stress, during exercise or in hypoglyceamic states. Furthermore the release of adrenaline and nor-adrenaline has a vasoconstrictive effect (Ryan, 1973). The extreme reactions to cold are accompanied by variation in skin color (Ryan, 1973).

Localized erythematous eruptions are caused by trauma, heat, chemical irritants, light or cold. Erythema is due to an increase of blood within the small vessels of the skin. The distribution is at times quite bizarre. *Flushing* of the skin, usually the face, is a special type of transient erythema. Blushing is a form of flushing caused by emotional factors and influenced by autonomic or endocrine activity changes or by direct action of vasoactive chemicals in the blood vessels in the dermis.

4.4.3. Ageing of the skin

Every physiological period of time is associated with changes in response of the structure and function of the skin, to varying endogenous or environmental stimuli. Most of the skin changes during a life cycle are discussed by Jarrett (1974) and Rook (1979). In this chapter the changes of the skin due to senility are discussed. The changes present in the skin of the aged individual must be considered as the product of their genetically determined vulnerability and the external and systemic factors to which it has been exposed throughout life (Comfort, 1964).

The change in appearance is the result of changes in the epidermis and dermis e.g. a flattening of the epidermis with localized hyperkeratosis (solar or senile keratosis) and a diffuse reduction in the density of hair follicles. With ageing there is a progressive reduction in the number of dopa-positive melanocytes in exposed and unexposed skin (Fitzpatrick, 1965). In 50% of the individuals older than 45 years a patchy form of increased pigmentation occurs due to proliferation of melanocytes at the dermal-epidermal junction.

With age the elasticity in the dermis changes. Collagen becomes stiffer and less elastic with age, as a result of increased cross-linkage between collagen molecules (Montagna and Carlisle, 1979).

A reduction in the number of sweat glands and a reduced output per gland, is often seen in old age. Reduction of hormonal factors influence their sensitivity to adrenergic agents. Localized vascular dilatations are present due to loss of elastin in the blood vessels. This histological change in the epidermis and dermis results in a yellow discoloration of the skin (Jarrett, 1974; Rook, 1979). Additional factors are loss of vasculature, the accumulation of metabolic products and lipogenesis.

4.4.4. Inflammation of the skin

The signs of an inflammation are erythema, swelling (edema), heat, itching and pain respectively. Redness is determined by the amount of red cells or of haemoglobin in the skin. The superficial dermal vessels are dilated and the flow is decreased. Depending upon the intensity and form of the inflammatory changes the redness may also result from stasis and congestion without increased flow of blood (Parish and Ryan, 1979). This partial stasis increases the opportunities for leucocytes to emigrate from the vessels (Ryan, 1973). A rapid swelling is due to oedema, by the increased leakage of water, mineral salts and plasma proteins from the blood vessels. This process may be followed by the infiltration of leucocytes. This is followed by neutrophils, macrophages and lymphocytes at a later stage. In the presence of edema the chromophore bilirubin bound to serum albumin may increasingly be present in the connective tissue (extra-vascular) (Ballowitz et al., 1970; Hanneman et al., 1978).

The skin temperature may rise as a direct result of a local increase in metabolic rate. Heat loss cannot be correlated with redness, because areas of fast blood flow in the capillaries may be on the border of a more congested and slow-flowing system (Parish et al., 1979).

The close physiological interdependence between epidermis and dermis and between the skin and changes in the blood

vessels result in changes of the epidermis manifested by hyperplasia, cell swelling (vacuolation) and coagulative degeneration (Parish et al., 1979).

4.5. The modes of appearance of the skin

The radiation transfer of light in skin is determined by the complex structure of skin layers and its presence of structures such as hair follicles, sweat glands and sebaceous glands. Radiation transfer of light in skin occurs according to four basic principles which are schematized in figure 4.2.

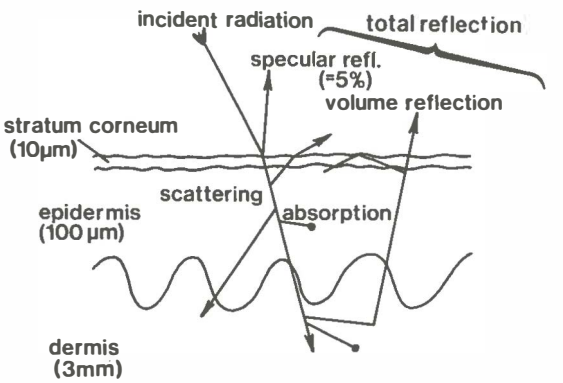

Figure 4.2
Schematic diagram of optical pathways in skin.

- *specular and diffuse reflection* at the boundaries of each layer due to differences between them in refractive index.
- *scattering and volume reflection*, the direction of radiation is altered by particles, fibers, organelles and cells within the layer.
- *absorption*, which may lead to photochemical reactions or

dissipation of the absorbed energy via heat production, fluorescence or phosphorescence.
- *transmission* through the layer (Parrish et al., 1978; Ten Bosch, 1980).

We have seen in chapter 3 that the color of the human skin is characterized by the reflectance spectrum with wavelengths within 400-700 nm.

4.5.1. The constitutive appearance of the skin

Besides the presence of different layers in the skin, there are chromophore molecules which exert a significant effect on the diffuse reflectance of the human skin. Studies of reflectance spectra in the skin by Edwards and Duntley (1939) showed diffuse reflectance minima of the cutaneous pigments melanin, oxy- and reduced hemoglobin (542 and 576 nm) and carotenoids (mainly β-carotene; λmax = 482 nm). A study by Ballowitz et al. (1970) has shown that bilirubin (λmax = 460 nm) may be added to this list of chromophore molecules within the visible spectrum. Outside this wavelength region epidermal aromatic aminoacids (λmax = 280 nm) and water near the infrared absorption bounds (Kuppenheim, 1952) are additional chromophore molecules.

Other particles are present in the skin which cause scattering. The degree of scattering depends upon the size of the particle. If the size is 1/100 of the wavelength, the amount of scattering varies inversely with the fourth power of the wavelength (Rayleigh scattering). A brief description is necessary for a good understanding of these physical processes. The amount of scattering is reduced if the particle size is equal to the wavelength and is independent of wavelength for large particles (Mie scattering). The inverse relationship between molecular and small particle scattering and wavelength creates an effectively shallower depth of penetration for shorter wavelengths than for longer ones.

The probability of a photon being absorbed in a medium is proportional to its pathlength. Scattering increases the effective pathlength. The penetration of different wavelengths depends also upon the presence of optically absorbing pigments (molecules).

Direct or regular reflectance from the skin surface is due to the difference in refractive index of air and stratum corneum (N_D = 1.55) and is only about 4-7% for perpendicularly incident radiation because of the nonplanar surface of the skin (Scheuplein, 1964).

Diffuse reflectance from the skin is largely from within the tissue, the absorption maxima of certain skin pigments are identified as minima in the spectral reflectance of the skin in vivo. Our perceptions of skin color are largely determined by the concentration and location of skin pigments and the optical interactions between the different skin layers.

Several authors have proposed a theoretical model of the penetration and reflection of visible radiation in the skin. The most important will now be described in a historical sequence.

Edwards and Duntley (1939) assumed that the color of the skin is determined by five pigments and an additional optical effect e.a. scattering in the turbid stratum mucosum. The pigments melanin, melanoid, carotene, reduced haemoglobin and oxyhaemoglobin absorb heavily in the blue end of the spectrum. The turbidity of the epidermis causes scattering which raises the blue end of the spectrum. This optical process prevents the skin from appearing dark red.

Findlay (1970) studied the apparent paradox whereby a brown pigment appears blue when located in the dermis. He demonstrated that the epidermis was not involved in this effect. Increasing thicknesses of connective tissue were examined by means of reflectance spectrophotometry. The observed reflectance spectrum was considered a consequence of both the wavelength dependence absorption and scattering

of light by the tissues. Red wavelengths were only slightly absorbed and scattered, therefore a relatively greater thickness of tissue is required in an increasing amount of reflected light. Blue wavelengths gives the reversed effect. The effect of radiation on the dermis in vitro results in a dark blue visual color. With the epidermis replaced on the dermis, the combination appears paler and greener by intensifying the diffuse reflection on the red side of the blue peak.

A discussion by Atkins (1969) was presented of a modified Kubelka-Munk diffuse flux theory, which is relevant to a quantitative theoretical model of the penetration and reflection of optical radiation in skin. This quantitative model was further worked out by Anderson et al. (1979) and Dawson et al. (1980).

Anderson et al. (1979) analysed the transmittance and reflectance spectra (320 nm-1000 nm) of human dermis and epidermis using a simple radiation transfer model. Their findings should be interpreted with reservation because their use of a collimated beam was not in accordance with the requirements of the Kubelka-Munk flux model. Results from a dermal sample over the spectral region of 300 nm - 800 nm suggest that scattering may arise primarily from structures with a dimension on the order of 1000 Å. Collagen fibers have approximately this order of diameter. The inverse relationship between scattering and wavelength largely accounts for the fact that shorter wavelengths do not penetrate the dermis to the same extent as do longer wavelengths. The diffuse-radiation absorption coefficient was found to be remarkably flat and small in comparison with the scattering coefficient(s). The marked increase of absorption coefficient (K) in the ultraviolet spectral region may be due to many chromophores present in the dermis.

Dawson et al. (1980) developed a theoretical model for the optical properties of a layered structure which absorbs and scatters light. This theoretical approach was also based

on formulae by Kubelka. Their simplified model took account of four skin layers: a fibrous protein layer (stratum corneum), a melanin layer, a haemoglobin layer and a collagen fat layer. These layers are assumed to compose of light absorbing and scattering particles, whose dimensions are much less than the thickness of the layer. They predict that the Logarithm of the Inverse Reflectance (LIR) of the surface (optical density) will be a useful parameter, to estimate absorbance. It was found that the LIR spectrum of normal skin is dominated by the summed absorbances of haemoglobin and melanin with small contributions from fibrous protein, collagen and fat.

4.5.2. The facultative appearance of the skin

The quantity of blood in the dermis, particularly the subpapillary venous plexus contributes to short term color changes in the skin (Dawson, 1980). Variation in blood flow and the proportion of oxyhaemoglobin to reduced haemoglobin give rise to rapid changes in skin color. According to Fox (1964) there is a weak correlation between the amount of blood present in the skin and the rate of flow through skin vessels. Findlay (1970) stated that the haemoglobin can react also as an example of dichroïsm e.a. the thickness difference of a layer of haemoglobin may cause a change in hue because of the change in the concentration of an absorber. Variations in blood flow of the subpapillary, blood vessels occur in several circumstances. The most important are discussed.

4.5.2.1. Cold environment

Exposure to cold, causes a reduction in the peripheral blood flow, with a secondary drop in the skin temperature (reducing the heat loss by radiation and convection). The amount of peripheral blood flow is reduced and at the same time in the deeper capillaries and veins increased (Åstrand, 1977). This results in a reduction of the radiation absorb-

tion in the green part (λ = 540-576 nm) of the spectrum because of a reduction of the amount of haemoglobin in the peripheral vascular plexus. The degree of scattering changes only slightly. The change in appearance impression results in a blanching skin. At lower temperatures the O_2-dissociation curve shifts to the oxygen haemoglobin content of the vessels. This results in an increasing redness of the skin.

4.5.2.2. Heat environment

Exposure of an individual to a hot environment causes vasodilatation in the skin and an activation of the sweat glands. The result is cooling through the evaporation of sweat. The appearance changes as a result of an altered refractive index of the wet skin surface, the increased amount of haemoglobin in the superficial vascular plexus with increased spectral radiation absorption in the green part of the spectrum. The relative increased thickness of the haemoglobin layer decreases the penetration of longwave spectral radiation to the collagen and fat layer. This increases the amount of scattering of this layer to some extent. The change in the appearance depends upon the balance between the degree of decrease in reflectance in the green, as well as in the red part of the spectrum.

4.5.2.3. Muscular work

The increased heat production due to muscular work is released from the body by an increased radiation, convection and an increased evaporation. Vasodilatation of the peripheral blood vessels occurs and results in an increased evaporation. The change in appearance of the skin is comparable to the exposure to a hot environment. A complicating factor is that the increased evaporative rate may cause a cooling of the skin, with resulting vasoconstriction.

4.5.2.4. Ultra-violet radiation

The erythematous and melanin effects on the skin exerted by UV-B (290-320 nm) and UV-A (320-400 nm) has been quantitatively worked out as the logarithm of the inverse reflectance or optical density by Anderson et al. (1979) and Dawson et al. (1980). The in vivo absorbance spectrum of skin in various racial groups differs considerably. When the average absorbance spectrum of a group of Caucasian subjects is subtracted from that of a group of negro subjects, the difference spectrum is obtained. This is attributable to a difference in amount of melanin and shows a remarkably linear spectral curve. The erythema index of four groups studied were independent of the melanin content of the skin.

Short term exposures to UV-B (delayed erythema) cause an increase in the absorption bands of oxyhaemoglobin (416, 542 and 576 nm) and bilirubin (460 nm) (Anderson, 1979). Longterm exposure of the skin to a 38 days Puva therapy shows an increase in the melanin content of the skin as well as erythema index (Dawson, 1980).

The changes in skin color due to active irradiation is based only on variations in the amount of secretory activity of melanin present and not on the number of melanocytes (Edwards et al., 1939). Skin color in the different races is largely determined by the packing, distribution and degradation of melanosomes within the keratinocytes (Fitzpatrick et al., 1979).

Spectrophotometric evaluation of the intra-individual skin color differences in summertime was performed by Kuppenheim et al. (1952) in skin areas with different degrees of suntan. Their findings showed the almost parallel difference in the spectral reflection curve of untanned and tanned skin as well as white and negro skin. There was a tendency for the difference to disappear with increase in wavelength. There was a wide individual variation in the results.

4.5.2.5. Ageing

The change in the appearance of the ageing human skin is the result of the histological alterations described in chapter 4.4.3. Increased wrinkling of the surface may decrease the specular reflectance of the skin. The decreased amount of sweat glands may reduce this regular reflectance too.

The flattening of the epidermis and the increasing width of the collagen bundles may affect the scattering of light, which results in a parallel decreased reflectance curve for men and women above 30 years of age (Buck et al., 1948). The change in appearance results in a yellowing of the skin, with a superimposition of localized vasodilatations and local hyperkeratosis. According to work of Zabel (1979) it seems to be that the ultraviolet sensitivity of human skin is neither correlated with age nor season. The range of ultraviolet sensitivity is more extended, in older people than in young ones.

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CHAPTER 5

THE VARIATION OF SKINCOLOR IN DIFFERENT AREAS OF THE HUMAN BODY IN A CAUCASIAN POPULATION IN CIE 1976, L*, u*, v* COLOR SPACE

Robert P. van Oort, Jaap J. ten Bosch, Peter C.F. Borsboom

5.1. Abstract

The prosthetic rehabilitation of patients with a defect in the facial region requires color matching of the prosthesis to the adjacent skin. The investigation of the skin color and the relation between skin colors of different easily accessible skin regions was carried out using a subtractive colorimeter. This method was verified using a spectrophotometer.

The objective measurement of the color of the skin is possible if the diameter of the viewing field is taken into account. The data from the spectrophotometer with 5 mm viewing field agreed closely with the results of the subtractive colorimeter. Mean and standard deviations of the color indices in three investigated areas of a population sample are given.

*The data presented in this chapter were previously presented at the 1979 meeting of the International Association for Dental research in New Orleans and published in J. soc. cosmet. chem. 32:1-14, 1981. Reprinted with permission of the Society of cosmetic chemists, New York.

The inter-regional correlations of measurements of the color indices for the three measured regions palm, cheek and forearm were weak. The correlations between the color indices measurements were also weak, except for the inner side of the forearm. By means of factor analysis an overall characterisation of the human skin color is presented.

To apply the skin color measuring method to a color matching system for facial prothesis only the measurement in the relevant skin region would be reliable.

5.2. Introduction

One of the objectives of the rehabilitation of patients with facial defects is the inconspicious reconstruction of this defect as soon as possible after operation or trauma. The color match of the prosthesis to the surrounding skin is one of the criteria involved in achieving this objective and, ideally, should be non-metameric. The prosthetic replication of the skin color requires a color system i.e. a procedure of adjusting colorant mixture until all visually apparent differences are eliminated in skin color. Many color matching procedures for facial prostheses have been developed recently mainly based on artistic procedures and reproducible color shade guides (1,2). Evaluations of the results of different color matching procedures are not available in the literature. In practice such non-quantitative systems prove to be unsatisfactory in producing an adequate match, especially when taking into consideration length of treatment time and costs. Also evident is the metamerism problem due to the differences in spectra of skin and prosthesis. These differences are present because the natural skin colorants are instable in vitro and therefore cannot be used as a prosthetic material.

To improve the color matching procedure and to quantify such a system the purpose of the present study involves:

Firstly, the instrumental and quantitative assessment of the variation distribution, difference and correlation of skin color of different parts of the body. The sample population consisted of Caucasian males and females. Secondly the assessment of the absolute values of skin color was also worked out from a spectrophotometric measurement of the skin of eleven subjects.

Several methods have been employed to study the color of the skin. Edwards and Duntley (3) performed spectrophotometric measurements of the skin and its pigments in 10 subjects of differing races. This work was concerned with the biophysical and biochemical analytic properties of human skin.

Buckley and Grum (4) did spectrophotometric measurements on the region of the cheek and converted the mean reflectance curve of 10 white subjects into CIE 1931 color specifications. Weiner and Lasker (5,6) introduced two different photovoltmeters in the anthropological field studies, which were directed towards inter- and intrapopulational comparisons of skin color for small wave length regions. Since then Lontz (7) has used the Hunter Lab. tristimulus colorimetric method for this work. However the latter investigators used too few samples to be of great value in estimating data for a population.

The limited applicability of the tristimulus colorimetric method was discussed by Billmeyer et al. (8). The main conclusion of this paper was that colorimetric methods in general can only be applied in measurements of color differences. For "absolute" color measurements a spectrophotometric method is required. On the other hand, if one demands easy and fast operation and a reasonable price, colorimeters are to be preferred. For our purpose of comparing the skin colors of various parts of the body and in different individuals in the population we selected a colorimetric method.

For the assessment of the mean and the spread of skin color in a given population we used a spectrophotometer for "absolute" color measurement. To facilitate relating the physical specifications of color stimuli to the visual perceptions that arise from them, all data were transformed to coordinates L^*, u^*, v^* of the approximately uniform color space (CIE, 1976).

5.3. Materials and methods

For the colorimetric measurements we used a Lovibond MK III (Tintometer Ltd, Salisbury, G.B.) with a movable measuring head connected with fibre optics of two meter length. We obtained serial No. AF 751-5271. All observations were done by the first author, his color vision was found to be normal by the Ishihara, the H-R-R test and the 100 Hue Farnsworth-Munsell test. The light source was specified as a CIE Illuminant C (approximately).

The skin is illuminated at an angle of 45^{o} to the surface. The measuring head prevents the leakage of light from the surroundings. The light reflected from an area of 25 mm^2 is received by a fibre optic perpendicular to the surface of observation (Figs. 5.1 and 5.2). A contact was maintained between the measuring head and the skin. The pressure never exceeded 13 mm Hg, or 1.7×10^3 N/m^2, i.e. below the subcutaneous capillary bloodpressure level (9). This was obtained by a constant force balance. Thermal effects were avoided because the measuring head was fabricated of thermally isolating plastic. Heating from the light was not commented on by the subjects.

The lovibond is a subtractive colorimeter which uses the Lovibond-Schofield system, i.e. a comparison field is visually matched to light reflected by the sample by means of colored filters. Only two out of three filter colors plus a neutral density filter were used to make a match. A

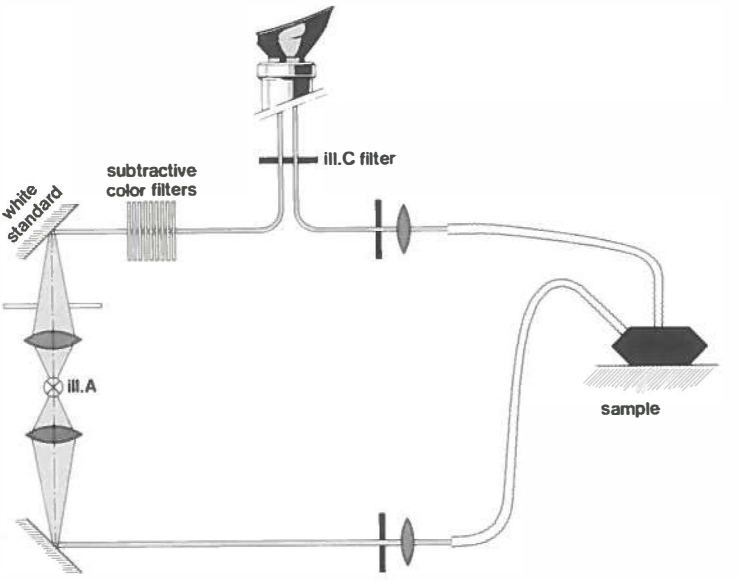

Figure 5.1

Schematic diagram of the Lovibond MK III subtractive colorimeter with fibre optics.

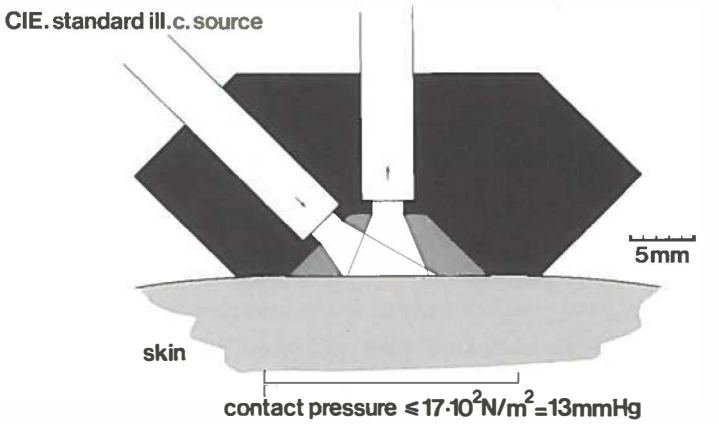

Figure 5.2

The measuring probe, showing the geometry of the light path. The maximal contact area is at a distance of 4 mm from the measuring area. The pressure is exerted by means of a constant force balance and is below the subcutaneous arterial and venous capillary blood pressure in the supine position of the patient.

bipartite field of vision of 2^{o} is used. The Lovibond-type color matches are only moderately metameric (10).

A spectrophotometric analysis of the Lovibond system was described by Haupt and Douglas (11) Computations by Haupt et al. (12) related Lovibond readings to CIE 1931 x, y (chromaticity coordinates) and Y (luminance factor). From these values the L*, u*, v* coordinates in the CIE (1976) Uniform color space were computed (13). In this color space equal distances between color points represent approximately equal perceptual differences, as long as distances are relatively small. For the present range of colors L* is related to brightness, the u* index is related to redness (+) versus greenness (-) and the v index is related to yellowness (+) versus blueness (-).

The sample was composed of a hundred dental patients which were referred to the department of oral surgery for treatment with minor oral problems. The patients originated in the northern districts of the Netherlands and contained no people evidently other than the white race. Patients with inflammatory lesions were excluded. They were measured in the 3^{rd} and 4^{th} week of January 1978. The median and mean age of the sample were 26 and 29 respectively. The youngest subject was 8 years, the oldest one was 76 years.

The subject sat upright in a dental chair with the right arm in a horizontal position resting in the elbow support. The observations were respectively taken at the thenar palm of the hand, the inner forearm and the infra-orbital region of the cheek. For each region the measurement took no longer than 1 minute. The subject was allowed to acclimatize from the outdoor temperature ($8-10^{o}$) to the micro-climate ($20 \pm 0,5^{o}C$) for at least 15 minutes. There was no direct sunlight in the room. The inner forearm of one male subject was too hairy to measure the skin color. The cheeks of the males and females were all free from cosmetics.

For the spectrophotometric verification measurement we used a Zeiss RFC-3.

5.4. Verification

The brightness reading on the instrument was calibrated by us using MgO surfaces and Munsell chips as described by the manufacturer. A chromaticity calibration was elaborated by the measurement of Munsell individual color standards (matte finish) of 3 x 5 inch in the gamut of the skin. The Lovibond data were compared with the tristimulus data provided by Munsell and obtained from General Electric spectrophotometer curves. Five Lovibond measurements of each standards were averaged. The Munsell standards chosen were: 5 YR 6/4; 5 YR 7/4; 7.5 YR 7/4; 10 YR 6/3; 10 YR 7/4; 10 R 6/4. (Table 5.1).

Later these standards were also measured with a Zeiss RFC-3 spectrophotometer. These data confirmed the G.E. Spectrophotometer data within $\pm$ 2% of L*, u* and v*. This is well in view of the different geometry of measurement of these two spectrophotometers.

Table 5.1

Means and Standard Error of Lovibond MK III and GE Spectrophotometric Measurements of Munsell Color Standards (3 × 5 in.)

10 YR 6/3	L^*	u^*	v^*
Lovibond	60.4 ± 0.3	13.5 ± 0.1	20.7 ± 0.1
G.E. Spectrophotometer	61.44	16.98	25.9
10 YR 7/4			
Lovibond	70.2 ± 0.6	20.2 ± 0.2	31.5 ± 0.5
G.E. Spectrophotometer	71.41	23.78	36.42
10 YR 6/4			
Lovibond	60.9 ± 0.18	27.1 ± 0.1	13.7 ± 0.2
G.E. Spectrophotometer	61.69	30.27	17.50
5 YR 6/4			
Lovibond	59.6 ± 0.6	24.6 ± 0.4	20.0 ± 0.7
G.E. Spectrophotometer	61.65	28.52	25.55
5 YR 7/4			
Lovibond	69.0 ± 2.2	24.3 ± 0.8	21.8 ± 0.8
G.E. Spectrophotometer	71.43	28.82	26.38
7.5 YR 7/4			
Lovibond	70.7 ± 0.7	22.8 ± 1.1	26.0 ± 0.5
G.E. Spectrophotometer	71.65	26.91	30.26

As Table 5.1 indicates, our Lovibond flexible optic Tintometer produced a desaturated color reading compared to the Munsell G.E. and Zeiss spectrophotometers. It appeared that the deviation was roughly in the same direction of the L*, u*, v* color space for all standard colors. Therefore all Lovibond measurements, except those in Table 5.1, were corrected with + 1.5; + 3.6; + 4.6; for L*, u* and v* respectively, being the mean color differences of the two instrumental readings.

For the spectrophotometric measurements of skin color a Zeiss RFC-3 with Serial Number 96870 was used. The skin of the forearm and palm was illuminated spherically, the measuring beam was at 8° with the normal. The field diameter was variable over 5 mm, 15 mm and 30 mm. The skin of the cheek could not be measured with this instrument.

The second sample was composed of eleven white subjects, 6 female and 5 male, and visually selected to rather extreme variance in skin color. The measurements took place in the third week of November 1979. The median and mean age of the sample were 28 and 29 respectively. The range was from 24 years to 45 years old. The results are shown in Table 5.2. A representative diagram of the differences of measurement in the L*, u*, v* colorspace between the Lovibond MK III and the Zeiss RFC with 30 mm field can be read from figure 5.3a and 5.3b for each subject separately. We presented only the data for outer forearm because this area has approximately similar pigmentation as the facial skin.

The differences in the measurement results between the Lovibond MK III and the Zeiss RFC-3 with 5 mm field diameter are small. The conclusion is justified that the different beam directions of the two instruments only affect the measurement results to a relatively small degree.

The difference between Lovibond and Zeiss with the field diameter of 15 and 30 mm is probably due to volume reflection of light as it penetrates a turbid medium like the skin.

Table 5.2

Means and Standard Deviations of Corrected Lovibond MK III Measurement (Values Corrected to Munsell Standards) and Zeiss RFC-3 Spectrophotometric Differences of Palm, Inner Forearm, and Outer Forearm for 11 Subjects with Increasing Field Diameter

	Lovibond values		
	L^*	u^*	v^*
Palm	56.49 ± 1.9	11.3 ± 1.4	11.78 ± 0.9
Inner forearm	62.88 ± 1.9	9.72 ± 1.6	16.81 ± 2.4
Outer forearm	55.55 ± 1.4	15.79 ± 2.2	21.28 ± 1.9
	Zeiss-Lovibond differences—Zeiss at 5-mm field diameter		
	ΔL^*	Δu^*	Δv^*
Palm	1.79 ± 1.6	3.5 ± 1.8	1.6 ± 1.3
Inner forearm	1.07 ± 0.8	2.8 ± 1.9	1.65 ± 1.7
Outer forearm	2.1 ± 1.8	2.92 ± 1.8	1.66 ± 1.4
	Zeiss-Lovibond differences—Zeiss at 15-mm field diameter		
	ΔL^*	Δu^*	Δv^*
Palm	3.97 ± 2.2	10.24 ± 2.5	3.62 ± 1.8
Inner forearm	3.7 ± 1.4	8.7 ± 1.9	4.7 ± 1.7
Outer forearm	4.15 ± 2.9	9.69 ± 2.5	4.17 ± 1.5
	Zeiss-Lovibond differences—Zeiss at 30-mm field diameter		
	ΔL^*	Δu^*	Δv^*
Palm	6.62 ± 2.0	12.1 ± 2.0	6.44 ± 1.5
Inner forearm	4.60 ± 1.5	11.55 ± 2.4	5.18 ± 1.6
Outer forearm	6.07 ± 3.0	10.86 ± 2.3	5.62 ± 1.8

Besides penetration, the scattering process also causes light travel parallel to the surface. This results in relative loss of light and hence a lower L*, when a small area is used. This phenomenon together with the different volume reflection coefficients of the shorter and longer wavelengths also explains the relatively larger redness-value(u*) of the spectrophotometric measurement with the largest viewing opening compared to the smallest opening. Also, absorption differences due to these pathlength differences may play a role. These effects will be further investigated.

The problem of the measurement of the translucent medium was discussed by Hunter (17). He advises using an instrument with an illuminating beam of smaller diameter than the diameter of the viewing window itself. The difference between the diameters of the window and the beam should

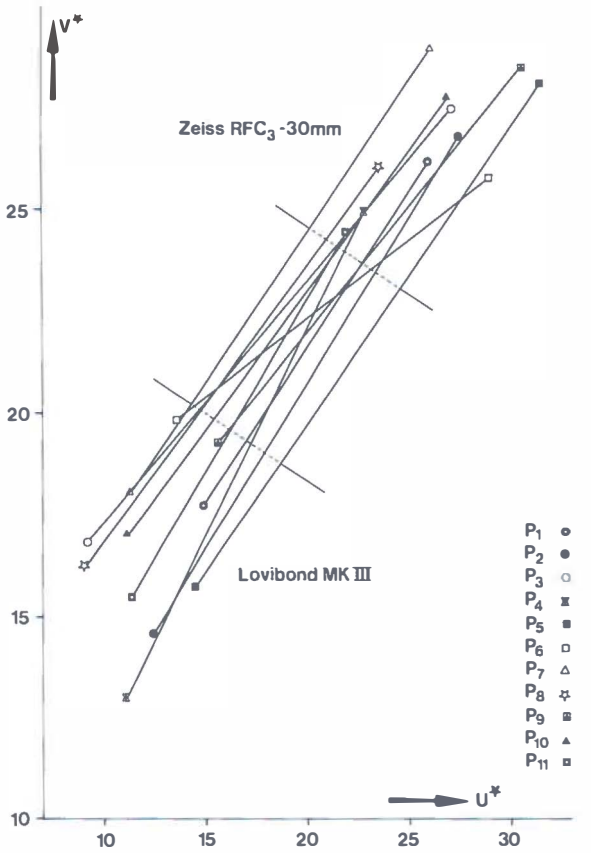

Figure 5.3a
u-v* color differences of the outer forearm of 11 persons measured using Lovibond MK III versus Zeiss RFC-3 with 30 mm viewing field diameter. The dotted lines represent the boundaries of the measurements of the two instruments.*

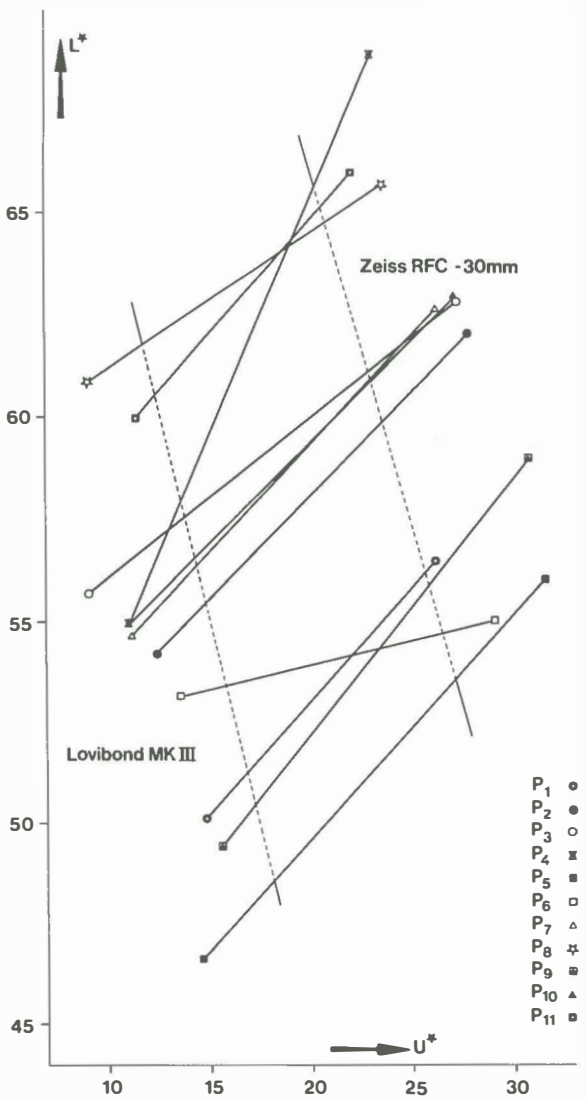

Figure 5.3b
L-u* color differences of the outer forearm of 11 persons measured using Lovibond MK III versus Zeiss RFC-3 with 30 mm viewing field diameter.*

increase with depth of light penetration of the specimen. However, because of the curvature and pliability of the skin we do not recommend the use of such a large field diameter, because the skin of the palm and the arm has a tendency to bulge into the measuring sphere. For the cheek this penetration is stronger.

5.5. Results

The precision of measurement at the same occasion was determined by ten repeated measurements after repositioning of the measuring head in one subject by one observer. For the skin in the zygoma area the standard deviations were found to be 1.1; 0.5; 0.9; for L*, u*, v* respectively. However in more color saturated skin areas these values were 1.8; 0.9; 0.7 for L*, u*, v* respectively. This increase of standard deviations was confirmed by measurement of the Munsell standards with increasing color saturation.

The magnitude of normal variation caused by time and precision of measurements, was registered in one subject by means of 9 measurements, in the zygoma area three every hour during morningtime. The standard deviations were 1.9; 0.6; 0.8 for L*, u*, v* respectively.

The skin color measurements of 100 subjects demonstrate an approximately normal distribution of the color indices of the forearm, the palm and the cheek. In figure 5.4. these distributions are shown for u*.

The means and standard deviations of u*, v*, L* indices for the three measured skin areas are shown in Table 5.3.

Only for the palm and the cheek is the difference for the mean u* between females and males significant ($P < 0.05$). L* and v* do not differ significantly between male and female.

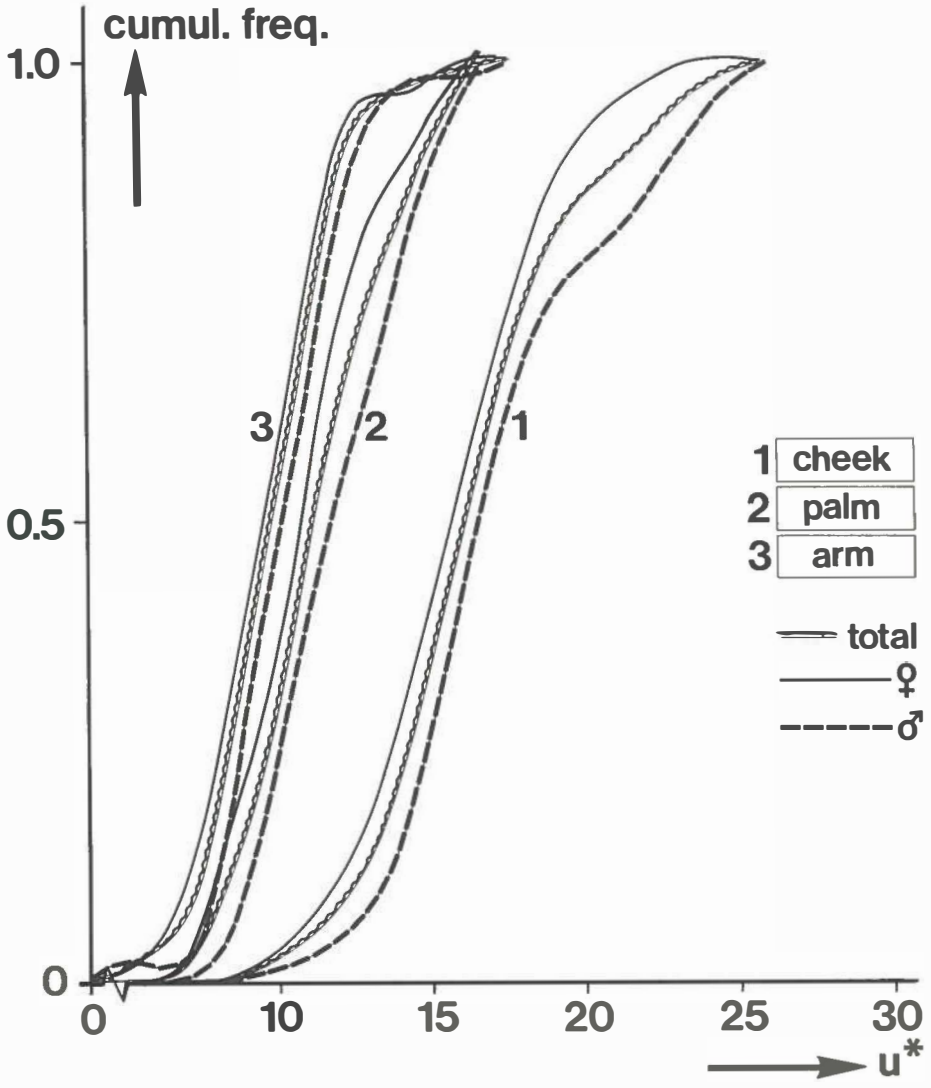

Figure 5.4

The relative u color coordinates for the inner side of the forearm, the thenar palm of the hand and infra orbital area of the cheek are approximately normally distributed over the populations.*

Table 5.3

Means and Standard Deviations (Denoted with S.D.) of the Sample (Values Corrected to Munsell Standards)

		N	L^*	S.D.$_{L^*}$	u^*	S.D.$_{u^*}$	v^*	S.D.$_{v^*}$
Inner Forearm:	Male	48	57.0	5.9	10.2	2.1	13.0	2.4
	Female	51	56.1	5.3	9.5	2.1	12.2	2.3
	Total	99	56.5	5.6	9.8	2.1	12.6	2.3
Palm:	Male	49	51.4	5.0	11.9	2.4	9.6	2.1
	Female	51	52.7	5.2	10.8	2.3	9.9	2.2
	Total	100	51.8	5.2	11.4	2.4	9.7	2.1
Cheek:	Male	49	45.8	7.3	17.4	3.6	10.5	2.3
	Female	51	47.2	7.5	15.8	3.0	10.8	4.2
	Total	100	46.5	7.4	16.6	3.4	10.7	3.4

The u* colorindex (redness), the v* colorindex (yellowness) and the L* index of the three skin areas of the subjects are not related to the ages of the persons. For the index u* this is illustrated in figure 5.5. The results for v* and L* are similar.

The correlation of the chromaticity indices u* versus v* and for u* versus L* for every measured area separately is given in Table 5.4.

The statistically significant correlation ($P < 0.01$) u* versus v* for the arm and the absence of u* versus v* correlation for the cheek can be read from the scatter diagram figure 5.6.

The color index relations between the three areas are quantitatively represented in Table 5.5.

To discover an overall relationship in the three color indices, measured in the three areas for the sample of 99 subjects a factor analysis was carried out. Every subject of the sample is characterized by nine variables i.e. 3(L*, u*, v*) times 3(palm, cheek, arm). Three factors are orthogonally rotated according to the varimax criterion (14, 15). The loading is a measure of the correlation between the factor and the variable. The results are presented in Table 5.6.

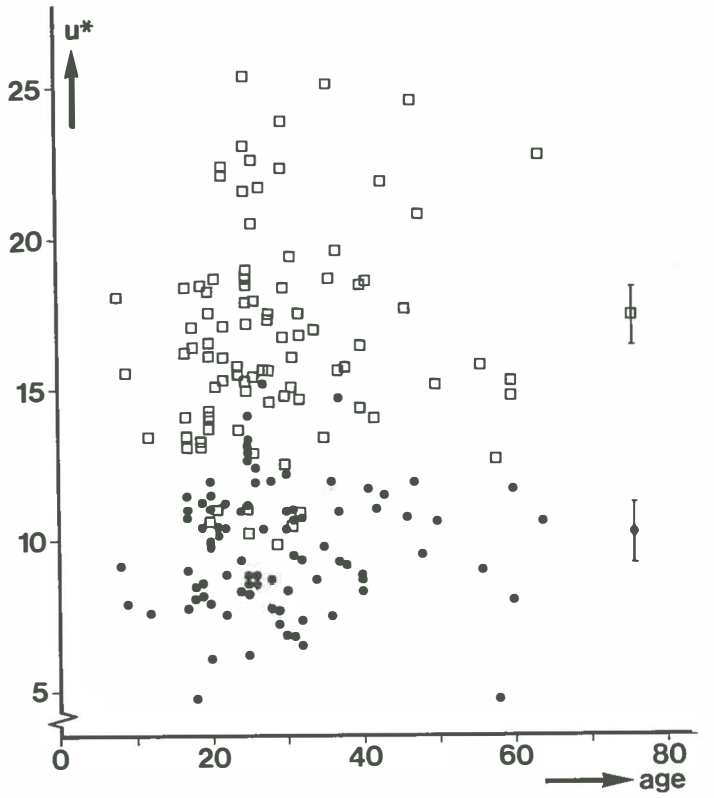

Figure 5.5
Scatter diagram of u versus age of the inner forearm and the cheek . A weak correlation is present.*

Table 5.4

Summary of Correlation Analysis of u^* Versus v^* and u^* Versus L^* and v^* Versus L^*. r is the Correlation Coefficient, P is the Level of Significance. N.S. Indicates $P > 0.05$

	N	$r_{u^*v^*}$	P	$r_{u^*L^*}$	P	$r_{v^*L^*}$	P
Palm:	100	0.28	<0.01	−0.25	<0.05	0.17	N.S.
Cheek:	100	0.06	N.S.	−0.41	<0.001	0.21	<0.05
Arm:	99	0.61	<0.001	−0.03	N.S.	0.16	N.S.

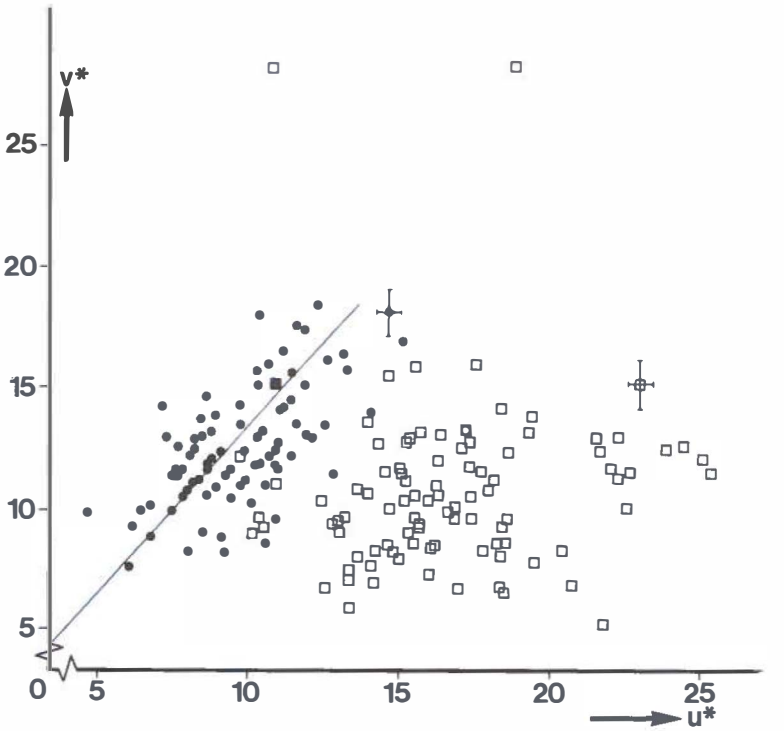

Figure 5.6

Scatter diagram of u versus v* for the inner forearm and the cheek . Only the correlation $r_{u^*v^*}$ of the inner forearm is significant P < 0.001. The regression equation for the forearm is v*= (2.6 ± 0.7) + 0.56 u*.*

Table 5.5

Summary of Correlation Coefficients *r* Between the Three Areas. *P* is the Level of Significance. N.S. Indicates $P > 0.05$

	N	*u**	*P*	*v**	*P*	*L**	*P*
r Palm/Cheek:	99	0.14	N.S.	0.17	N.S.	0.28	<0.01
r Palm/Forearm:	99	0.32	<0.01	0.25	<0.02	0.31	<0.01
r Cheek/Forearm:	99	0.27	<0.01	0.33	<0.01	0.31	<0.01

Table 5.6

Table VI

Variables	Orthogonal Rotation of Factors		
	1	2	3
V1 u^* palm	.647	−.484	−.034
V2 v^* palm	.518	.065	−.033
V3 L^* palm	.071	.825	−.041
V4 u^* cheek	.254	.175	.854
V5 v^* cheek	.531	.303	−.137
V6 L^* cheek	.216	.352	−.797
V7 u^* inner forearm	.774	.058	.170
V8 v^* inner forearm	.704	.301	.104
V9 L^* inner forearm	.197	.619	−.024
Explained Variance (%)	27.31	18.04	13.43

The first factor has positive loadings. Its high loadings are for V1, V2, V5, V7 and V8, or redness index and yellowness index for the palm and the innerforearm and the yellowness index of the cheek. This is a factor of chromaticity.

The second factor has positive factors except for redness index of the palm. Its high loadings are for V3 and V9, luminous reflectivity of the palm and the inner forearm. This is a luminous reflectivity factor, excluding the cheek.

The third factor is certainly puzzling with negative and positive loadings. Its high loadings are for V4 and V6. The main emphasis of this factor seems to be on the pigmentation of the facial skin.

5.6. Discussion

The precision of measurement on a particular skin sample tends to be inversely related to its saturation. Psychophysical color difference measurements converted in the L*, u* and v* color space seem to confirm this (16).

The color of the skin is determined by the different translucent layers, the particular pigments in each of these layers and the degree of the light scattering due to

difference in turbidity (3). This translucency of the living human skin and its effects is difficult to investigate at the moment.

In maxillofacial prosthetics the main interest is directed towards the facial area. The results in color differences obtained by the colorimetric method between the three investigated areas show a significantly higher $S.D._{u^*}$ and $S.D._{L^*}$ ($P < 0.01$) (Viz. Table 5.3) of the melanin pigmented skin of the cheek than of the relatively unpigmented inner forearm. This relates to the "normal" population variation of pigmented areas. Furthermore, the significantly higher redness u^* value ($P < 0.01$) of the cheek and the palm in comparison to the forearm can be explained by the bodily distribution of arterial bloodsupply sizes of blood vessels and melanine content of the stratum mucosum and the epidermis(3). A similar explanation may hold for the higher v^* value of the inner forearm, which may correlate with a higher carotene content. The significantly lower L^* of the cheek ($P < 0.01$) and the palm ($P < 0.01$) compared with the inner forearm is probably caused by the degree of scattering due to a thicker stratum mucosum. The same explanation might hold for the negative relationship (Table 5.4) between u^* and L^* of the palm and u^* and L^* of the cheek which indicates the relatively large degree of light scattering in these skin areas.

The weak correlations of either u^*(redness) or v^*(yellowness) index between the three investigated skin areas (Table 5.5 and 5.6) indicates that it is useless to measure the color of the inner forearm or palm as a basecolor for the facial prosthesis. The instrumental determination of skin color and conversion and preparation of a color recipe should be exerted directly on the facial skin. The development of a preferably spectrophotometric instrument suitable for such an intricate situation is desirable for the near future.

The distribution of skin colors in our population in relative units can be determined from our colorimetric data. 95% of the population is within a width of four standard deviations. For the cheek the width of this range amounts to $\Delta L^* = 29.6$; $\Delta u^* = 13.6$; $\Delta v^* = 13.6$ (Viz. Table 5.3).

Absolute data can only be roughly derived assuming that the spectrophotometric values at 30 mm diameter correspond to visual perception of the skin. Then the mean and standard errors of the distribution of a skin pigmented similarly to the face amounts to $L^* = 61.63 \pm 1.4$; $u^* = 26.73 \pm 0.9$; $v^* = 26.9 \pm 0.4$.

Climatic, physiological and ethnical factors will probably make it necessary to modify these color data, before it will be applicable in the artificial cosmetic replication of facial skin. Such work is in progress.

Acknowledgements

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CHAPTER 6

VARIATION OF THE FACIAL SKIN COLOR DUE TO SEASONAL INFLUENCES AND TEMPERATURE REGULATION

Robert P. van Oort, Jaap J. ten Bosch

6.1. Abstract

The color match of a facial prosthesis to the surrounding skin may be deficient due to photobiological and vascular changes in the skin. A quantitative investigation of pigmentation and erythema (13 subjects), muscular work (13 subjects) and environmental cooling (8 subjects) was performed, using a subtractive colorimeter.
The photobiological changes were verified with a series of spectrophotometrical measurements.

The three different samples, with comparable biological variation of the chromaticity coordinates, in the three different experiments were measured according to standard procedures. The mean color differences of the photobiologically varying skin color in three different skin regions were twice as large as the variation in skin color due to muscular work and environmental cooling. The photobiological variation of skin colors are caused for the most part by a variation in the luminosity (L) and a variation in*

*Some of these results have been reported at the 1981 meeting of the International Association for Dental Research in Chicago and submitted for publication to the Journal of Investigative Dermatology.

redness (u^*). This was confirmed by the spectrophotometric measurement in wintertime and summertime, and the correlation ($r_{u^*,L^*} = -0.4$) of the colorimetric measurements during 1 year.

The skin color variation of both the muscular work, as well as the environmental cooling experiment, showed a large standard error and a return to initial values right after the experiment. Consequently the results of the photobiological experiment only determines the extension of the range of a color matching system.

6.2. Introduction

The prosthetic rehabilitation of patients with facial defects requires a color match between the skin and the facial prosthesis. The color match between the skin and the prosthesis may be deficient due to the photobiological influence on the skin, the variations in the cutaneous blood flow and the staining of the facial prosthetic material. A study of the photobiologic influence and the effect of muscular work and environmental temperature on the appearance of the skin is necessary for the development of a quantitative color system.

The difference of the chromatic appearance of the skin at two successive events is expressed in magnitudes of color difference. The L*, u*, v* color difference system is used to express the perceptibility of small contrasts in color.

A change in the color appearance of the skin by U.V.-light (290-400 nm) irradiation (U.V.A. + U.V.B) arises from the complex interplay of light and the epidermal melanin unit (Quevedo et al., 1974a; Fitzpatrick et al., 1971; Parrish et al., 1978). The complex reaction pattern of the skin on ultraviolet radiation is characterized by erythema (0-20 h) and tanning (1-72 h). Both are divided into an immediate and a delayed type of response (Quevedo, 1974;

Parrish et al., 1978). Marked regional variation over the human body appears to exist in the sensitivity of melanocytes to specific hormones as demonstrated by the number of melanogenic melanocytes (Quevedo, 1974).

Investigations dealing with the seasonal influence of U.V.-light on the epidermal-melanin unit are scarce. A longitudinal investigation of this effect is not found. The studies of Kuppenheim and Heer (1952) showed the marked differences in spectral reflectance curves between inside forearm, outside forearm, and the forearm for 113 white as well as negro subjects at the end of the summer. Seasonal variation of pigmentation of the face was described by Buck and Froelich (1948). Their average spectral reflectance curves showed relatively little change between spring and summertime, which was attributed to the exposure of the face to light throughout the year.

A change in the color appearance of the skin due to muscular work or a cold environment is caused by a vascular reaction. This reaction plays a role in the regulation of the deep body temperature in order to protect the body tissues from heating or cooling (Åstrand, 1977). Muscular work is attended with the release of heat. This energy is transported by the blood and lost through the apices of the capillary loops in connection with the arterio-venous anastomoses (Ryan, 1969). The heat is convected to the environment.

Environmental and local cooling influences the peripheral blood-circulation on several factors: a local vasoconstriction, an increase of the viscosity (Pringle, 1965), the lessened distribution of blood in the arterioles, in the capilaries, and in the arterio-venous anastomes and has influence on the oxygen saturation of this blood (Zijlstra et al., 1973).

This paper deals with the quantitative assessment of the skin color variation throughout the year as well as due to muscular work as well as due to a low temperature of the

environment. Furthermore the consequences for the color matching system of the facial prostheses will be analyzed.

6.3. Materials and methods

For the colorimetric measurements we used a subtractive colorimeter, a Lovibond MK III (Tintometer, Ltd., Salisburv. G.B.) with a movable measuring head connected with fibre optics of two meter length. All observations were done by the first author, his color vision was found to be normal by the Ishihara, the H-R-R test and the 100 Hue Farnsworth Munsell test.

The light source was specified as a CIE illuminant C (approximately). Pressure of the measuring head on the skin and thermal effects did not influence the skin color. The Lovibond values were transformed to L*, u*, v* coordinates of the CIE (1976) uniform color space by use of a computer program based on the spectrophotometric analysis of the Lovibond system (Haupt, Schleter and Eckerle, 1972). This method was verified by control measurements with a Zeiss RFC-3 with an adjustable measuring opening as described by Van Oort, Ten Bosch and Borsboom (1981).

The seasonal skin color investigation (first experiment)

The skin color was measured of 13 human volunteers on the infraorbital region of the left cheeck, the supra-orbital region of the left forehead and the inner side of the left forearm. Six women and seven male subjects, with ages ranging from 24-49 years (a mean age of 32 years and a median age of 30 years), were measured colorimetrically in the morning every three weeks from June 1978 till June 1979. The biological variations of the sample are described in Table 6.1. They were indoor employees for five days a week. The subjects were acclimatized for at least fifteen minutes in the measurement room (microclimate $20^{o} \pm 0.5^{o}$ C). The cheeks

of the females and males were all free from cosmetics.

The work load-skin color investigation (second experiment)

The skin color was measured on the infraorbital region of the left cheek. Ten male and three female volunteers, with ages ranging from 24-50 years (a mean age of 31 years and a median age of 29 years), were subjected to a standardized submaximal exercise test on a bicycle ergometer (Lode, HL 600 R). The biological variations are described in Table 6.1.

Table 6.1. Biological color variation of the cheek in the different samples in wintertime (means and standard deviations: S.D., corrected to Munsell standards)

	N	L^*	S.D.	u^*	S.D.	v^*	S.D.
seasonal influence	13	57.93	2.5	16.8	3.4	14.24	3.3
bicycle ergometer	13	57.5	3.2	18.0	3.4	14.6	2.7
refrigerator 4° C	8	59.5	3.3	17.7	2.0	16.0	2.6
population (v.Oort et al., 1981)	100	46.5	7.4	16.6	3.4	10.7	3.4

The exercise experiment started with a workload of 50 Watt. After every three minutes exercise the workload was increased with 50 Watt until the heart rate exceeded 160 per min. In that case the workload was increased with 25 Watt. After the heart rate had exceeded 175 per min. the workload was decreased to 50 Watt. This load was maintained during 12-15 minutes until the heart rate was stabile again. During the whole experiment the pedal frequency was kept at 60 revolutions per minute.

The subjects were acclimatized for at least five minutes in the measurement room (microclimate 20.5 $\pm$ 0.5° C, relative humidity 51 $\pm$ 1.5%). The skin color was measured at the

end of each 3 minutes period and at 3 minutes intervals during the recovery period. A rough estimation of V_{O_2} (max) was made from the heart rate for a given workload (Åstrand, 1977).

The measurement in a cold environment (4° C)(third experiment)

The skin color was measured at the infraorbital region of the left cheek. Six males and two females, with ages ranging from 24-49 years (a mean age of 31 years and a median age of 29 years), were colorimetrically measured in a refrigerator room with a temperature of 4° C. The biological variations are described in Table 6.1.

After the baseline measurement at room temperature (20° ± 0.5° C) the skin color was measured every one and a half minute with the volunteer in the refrigerator room. After ten minutes from the onset a fan was placed in the refrigerator room, 1½ meters in front of the volunteer for another three minutes, during which period two measurements were taken. After this period the subjects were acclimatized at room temperature for fifteen minutes. The skin color was measured seven times after the cooling period.

In the three different investigations the collected measurement data were elaborated separately and they were calculated in L*, u*, v* color-coordinates representing colorpoints in the CIE (1976) Uniform Color Space. Furthermore the range of the single skin color coordinates per subject per experiment was calculated. These ranges were averaged for every sample and expressed in R_{L^*}; R_{u^*}; R_{v^*}.

In between all L*, u*, v* measurements data all the color differences ΔE^*_{uv} (Wyszecki, 1978) were calculated for every experiment and for every subject separately. In order to take into account the error of measurement, the

three largest overall values ΔE^*_{uv}, were selected and averaged. These mean values per subject were averaged for the whole sample per experiment.

The L*, u*, v* coordinates of the median of these three largest ΔE^*_{uv} differences were selected. The range between the highest and lowest values of these median color coordinates was calculated per subject and averaged for each of the three experimental samples (D_{L^*}; D_{u^*}; D_{v^*}) separately.

The differences of the means were compared by the Student's t-test at a 95% level of significance. The differences in SD_{L^*}; SD_{u^*}; SD_{v^*} were compared by the F-distribution test at a 95% level of significance (Wesp, 1977; Clarke, 1980).

6.3.1. Evaluation and verification

In order to make an analyses between the error of measurement and the short term skin color variation (vascular effect), different samples were measured and compared (Clarke, 1980).

The error of measurement was determined in eight subjects. For each subject the measuring head was repositioned four times on the same skin surface, and readings were made. The mean and standard deviation of the measurements were calculated for each subject. The combined standard deviations of L*, u*, v* were calculated by means of

$$SD_{comb.} = \left\{ \frac{SD_1{}^2(N_1-1) + SD_2{}^2(N_2-1) + \ldots + SD_8{}^2(N_8-1)}{(N_1-1) + (N_2-1) + \ldots (N_8-1)} \right\}^{\frac{1}{2}}$$

in which $N_1 = + \ldots = N_8 = 4$.

The short term variation was determined in four subjects over three successive sunless days, after repositioning the measuring head in approximately the same facial skin region. Similarly the combined standard deviations for L*, u*, v* were calculated.

The range of the single coordinates of the error of measurement and the short term variation and the seasonal variation are given in Table 6.2. Although we assume that the seasonal variation is not drawn from a normal distribution the values are given for completeness.

Table 6.2. The combined standard deviations of L^*, u^*, v^* CIE, 1976.

		COMBINED STANDARD DEVIATIONS			THE RANGE OVER THE SUBJECTS(mean and s.d.)		
cheek	d.f.	S.D.L^*	S.D.u^*	S.D.v^*	RL^*	Ru^*	Rv^*
error of measurement	24	1.6	1.2**	0.9**	2.8±1.9	2.2±1.4	2.0±1.3
short term variation	67	1.5	1.8**	1.8**	4.6±1.7	5.0±1.5	4.4±1
seasonal variation	183	3.1	2.1	2.2	11 ±3.3	7.9±4.7	3.3±2.7
population variation (van Oort, 1981)	99	7.4	3.4	3.4	-	-	-

** F-distribution test; $p < 0.05$

There is a significant difference between the SD_{u^*} and SD_{v^*} of the error of measurement, and the short term variation of the cheek. This is probably caused by the vascular effect of the short term skin color variation. Other data in this Table are discussed in the results section.

The relative skin color one year around measurement was *verified* with the absolute skin color measurement by means of a spectrophotometer. As the skin of the cheek could not be positioned in front of this instrument the pigmented outerside of the forearm was measured in two samples of eleven and six subjects once in wintertime and once in summertime respectively.

6.4. Results

First experiment

For one example the skin color variation of the cheek during one year is shown in figure 6.1 for the L*, u*, v* color indices.

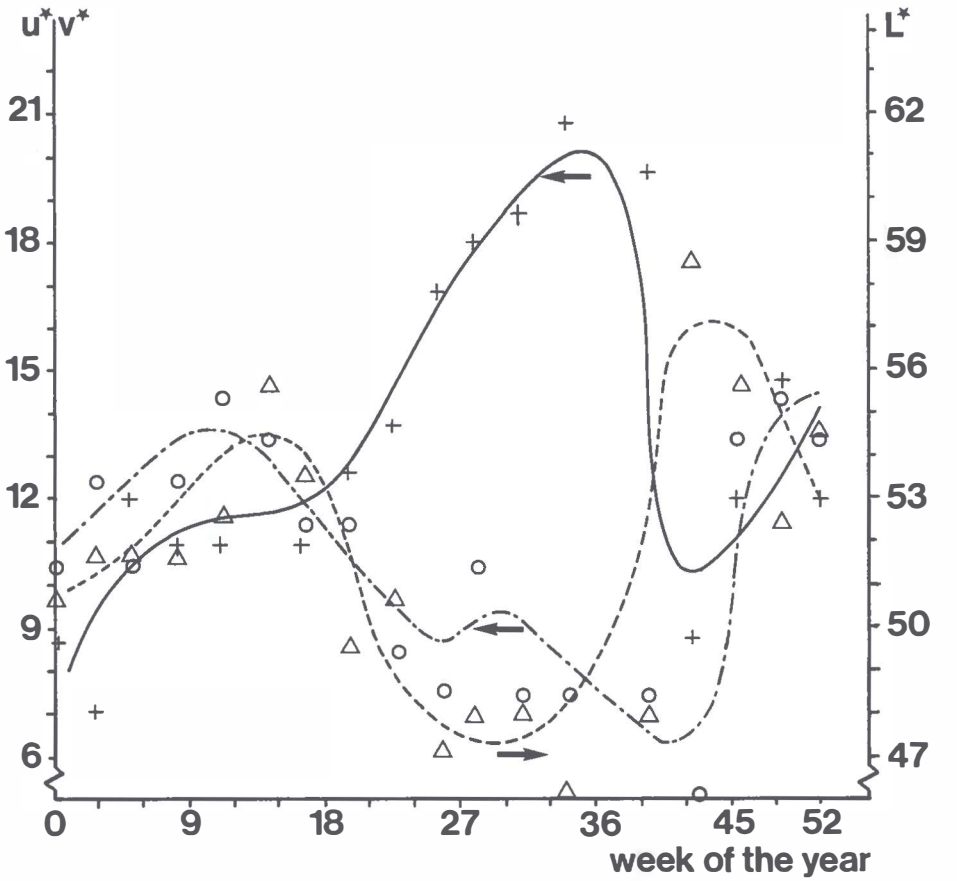

Figure 6.1
Seasonal color variation of the facial skin of a female subject, expressed in the color indices (L: --Δ; u*:— +; v*: ·-O) of the CIE 1976 Uniform Color Space.*

There is a significant negative correlation between the u^* and L^* indices. This systematic variation was also shown in most of the other subjects in the cheek and forehead regions.

A graphical presentation of the seasonal skin color variation for the whole sample is disturbed by the individual variation in time and period of holidays and periods in which much time is spent outdoors. Therefore the ranges between L^*; u^*; v^* of the cheek for the longterm variation per subject were averaged for the whole sample and compared with the ranges of the error of measurement and the short term variation (Table 6.2). It can be seen that the differences for L^* and u^* are significant between the seasonal variation and the error of measurement as well as the short term variation.

The mean of the three maximal color differences for each subject and the range of these median color differences are presented in Table 6.3.

Table 6.3. Seasonal variations, the median of three extreme values (N=13), mean and standard deviation.

	ΔE^*_{uv} N=13	DL^*	Du^*	Dv^*	ΔE^*_{uv} female N=6	ΔE^*_{uv} males N=7
inner forearm	12.9±3.4	10.5±3.9	4.9±3.1	3.7±2.6	13.8±4.3	12.1±2.4
cheek	12.2±3.0	9.5±3.0	5.6±3.9	2.9±2.3	14.0±2.9	10.6±2.3
forehead	13.0±2.5	8.8±3.7	5.2±2.1	6.4±4.1	14.0±3.0	12.1±2.2

It can be seen that there is no statistical difference between the three observed skin regions. Only the difference between the mean cheek values of ΔE^*_{uv} of the females and males is significant. The time elapsing between the highest and lowest ΔE^*_{uv} values was never less than nine weeks with a mean of 24 weeks.

The ranges in the color coordinates of the three largest values of ΔE^*_{uv} in each subject were plotted in a scatter diagram. The relationship of the color indices is significantly non zero for the $r_{Du^*DL^*}$ (-0.4) of the cheek (figure 6.2) which is in agreement with the relation, apparent in figure 6.1.

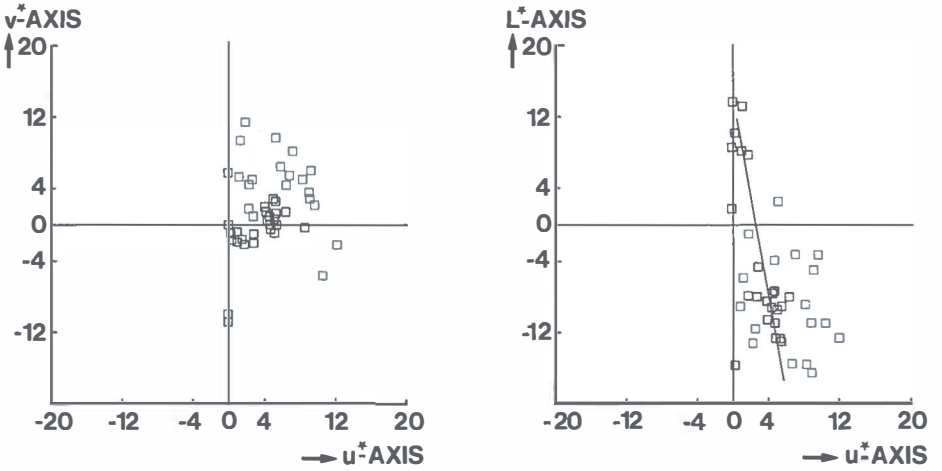

Figure 6.2
The quality of the three largest seasonal variations in every subject (N=13). The correlation coefficients equal $r_{Du^*Dv^*} = 0.1$ *and equal* $r_{Du^*DL^*} = -0.4$. *Only* $r_{Du^*DL^*}$ *is significantly non zero* $p < 0.05$.

The ranges of the median of these three extreme values ΔE^*_{uv}, D_{L^*}; D_{u^*}; D_{v^*} are relevant for the color matching system used for the manufacture of a facial prosthesis.

In the outer forearm, measured in wintertime and summertime (figure 6.3 and Table 6.4), the observed L*, u* effect is confirmed by the spectrophotometric analysis.

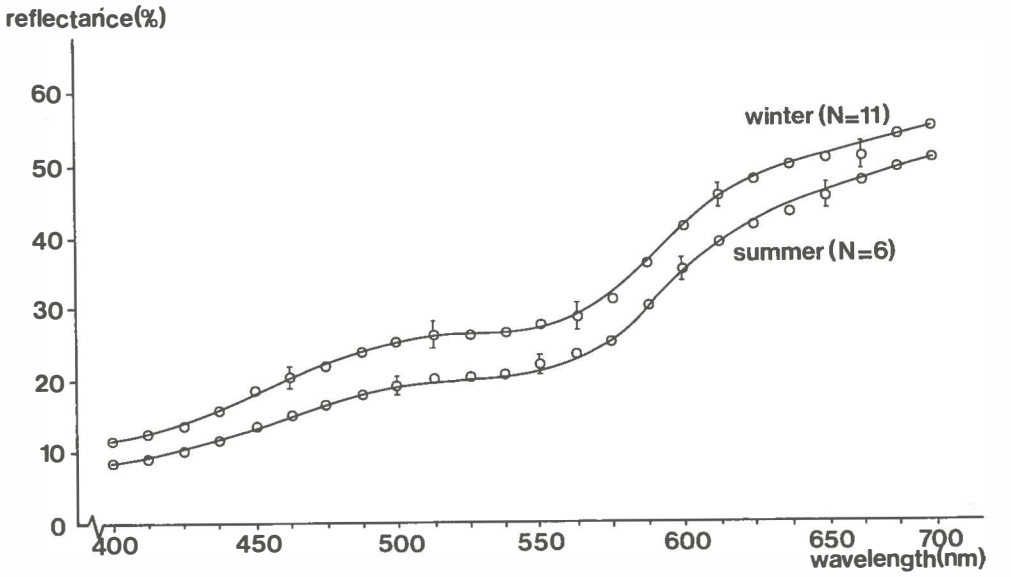

Figure 6.3
The average and standard error of the spectral curves (Zeiss RFC-3 with 30 mm viewing opening) of the outerside of the forearm in wintertime (N=11) and summertime (N=6).

Table 6.4. Spectrophotometric measurement of outside left forearm with Zeiss RFC-3 (30 mm viewing opening) mean and standard deviation

	N	L*	u*	v*
wintertime	11	61.6±4.5	26.7±3	26.9±1.4
summertime	6	56.6±2.7	30.0±1.8	27.4±1.8

Second and third experiment

The colorimetric measurements of the skin color due to muscular work load and cooling show a slight systematic variation.

For the two experiments the results were calculated in

ΔE^*_{uv} on the basis of the initial value and averaged. The results presented in figure 6.4 and 6.5 show the moderate color difference after 200 Watts work load and the slight color variation with large standard errors in the cooling experiment.

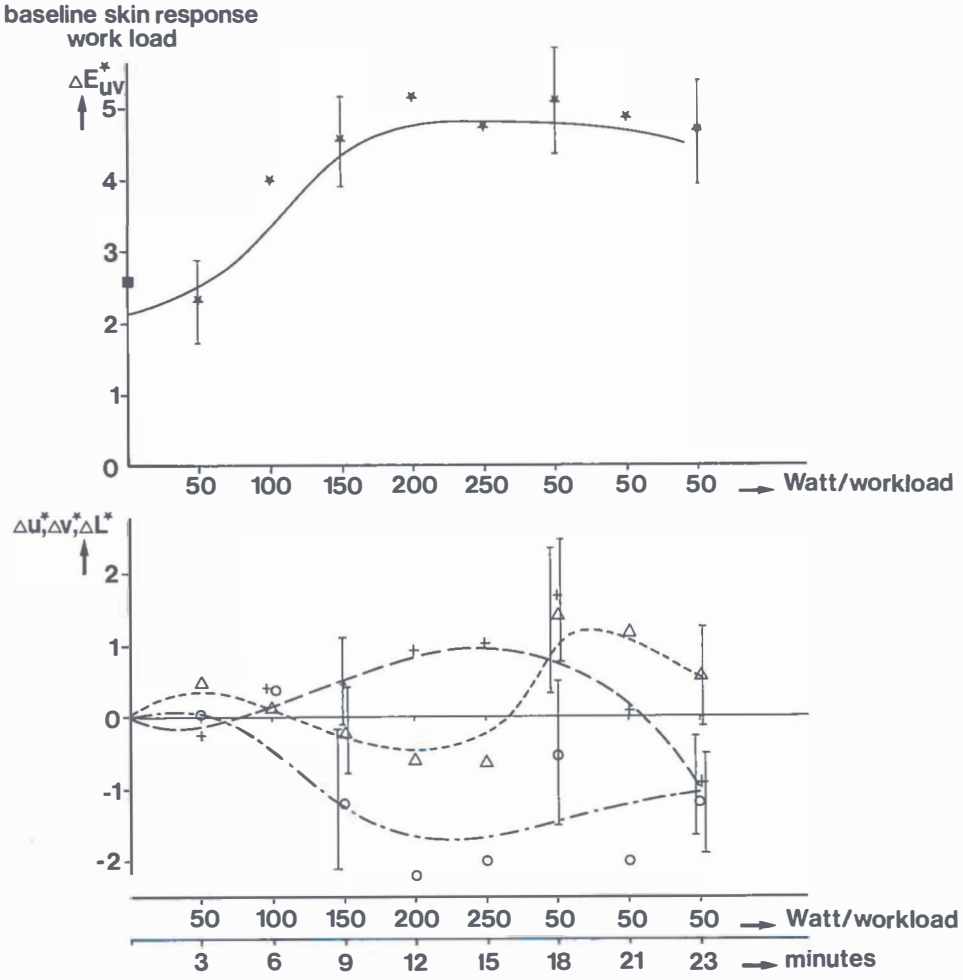

Figure 6.4

*Mean and standard error of baseline facial color difference (N=13) with increasing work load in Bicycle Ergometer experiment (ΔE^*_{uv}: *—; ΔL^*: --Δ; Δu^*: -+-; v^*: -o---). The initial value ■ (ΔE = 2.75) corresponds to the short term variation of the skin color.*

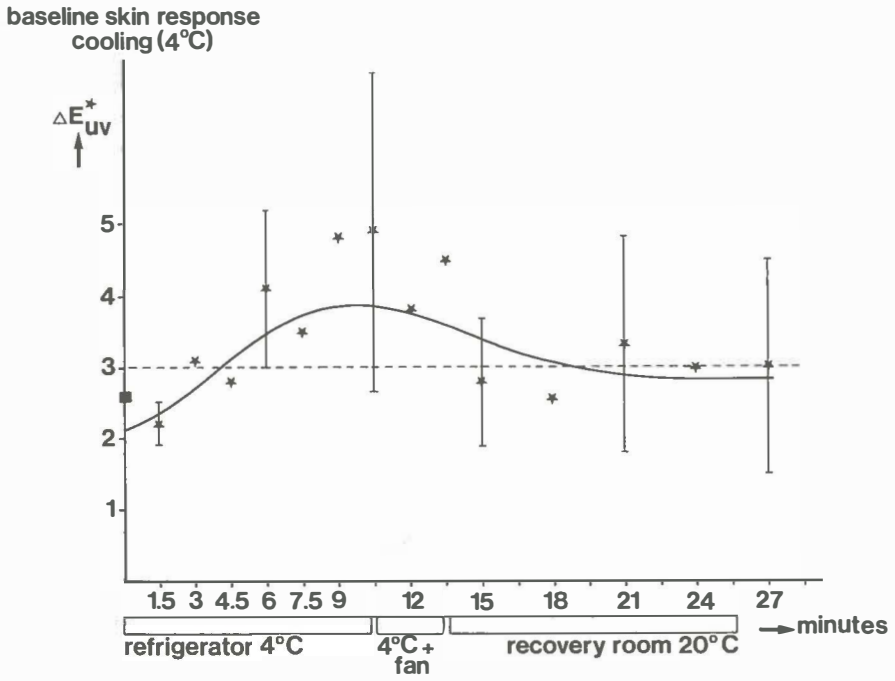

Figure 6.5

Mean and standard error of the baseline facial color difference (N=8) with environmental cooling in a refrigerator room experiment (4° C) (ΔE^*_{uv}: --). The initial value ■ (ΔE^*_{uv} = 2.75) corresponds to the short term variation of the facial skin color.*

6.5. Discussion

The different samples used in this study compared with the variation of skin color in the population (Table 6.1) showed that the distributions do have the same variance in the chromaticity coordinates. This null hypothesis is rejected for the L* (luminosity) coordinate in the sample. These individual differences may be caused by the larger number of outdoor workers in the sample of 100 subjects. Consequently,

caution should be exercised in extrapolating the results in this group to outdoor workers, to other ethnic groups and to other climates. Anyhow, the results in the present experiments are relevant for the facial prosthetic patients, because most of them are in the elderly age group and retired and thus mostly living indoors.

The Lovibond measurement shows less redness (u*) sensitivity compared to the Zeiss spectrophotometric (30 mm) skin reflectivity measurement (van Oort et al., 1981). Because this study only deals with relative measurements, this lower redness sensitivity may effect the color difference measurements to a lesser degree.

Since seasonal variation is ascribed to melanin pigmentation and erythema (Quevedo et al., 1974; Parrish et al., 1978) our results show that these effects are measured mainly by the L* color index and to a minor degree by the u* color index. This is verified by the difference between the mean spectral curves of wintertime and summertime (figure 6.3), which show an absorbtion over the whole visible spectrum due to melanin and absorbtion in the green part of the visible spectrum only, which is ascribed to blood (a.o. Anderson and Parrish, 1981).

The skin color variation due to muscular work and cooling is small when compared with the seasonal variation (figure 6.4 and 6.5). The observed effects are ascribed to the vascular dilatation and contriction of the skin blood vessels caused by the thermoregulation of the body. The parallel effect in muscular work is the activation of the sweat glands. At high evaporative sweat rates the skin may cool and the vasodilatation is reversed in vasoconstriction (Åstrand, 1977).

The results do have the following consequences. The visual matching of the prosthesis to the skin is disturbed for the most part by the seasonal influence on the skin. Mostly it is not disturbed by muscular work and cooling. The exertion of muscular work, as observed in every day life, is merely ob-

served by sweating and breathing rather than a facial discoloration. However, our observations indicate that the subjects with a low condition (V_{O2}(max)< 3 l/min.) show a color variation which is significant to the error of measurement (Table 6.5).

Table 6.5. Facial skin color variation due to muscular work and low temperature (4° C)

	N	degree of freedom	S.D.L*	S.D.u*	S.D.v*
error of measurement	8	24	1.6	1.2	0.9
bicycle ergometer	13	98	2.2	1.6	1.8
bicycle ergometer: Vo_2 max >3	9	71	2.1	1.4	1.8
bicycle ergometer: Vo_2 max <3	4	27	2.5	2.0	1.6
refrigerator room (4° C)	8	104	1.9	1.3	1.1

The low environmental temperature, which is comparable with the temperature in our climate, caused no facial discoloration. Facial reddening, due to a shift of the hemoglobine dissociation was not observed in our experiment (Zijlstra, 1973).

The results in this paper have two consequences for manufacturing the facial prosthesis:

Firstly: the L* color mismatch between facial prosthesis and the adjacent skin can be restored by applying, internally, melanin type pigments to the "winter" (base)color recipe. Such adjuvants-pigments are essentially grey. In addition an external coloring of the facial prosthesis may restore the altered u* and to a minor degree v* color mismatch, which changes the increasing resorption in the green part of the visible spectrum.

Secondly: the width of the range of the facial skin colors is important for the development of a color mixing system. In a former study (van Oort et al., 1981) the width of the range of skin colors was reported to be 29.6, 13.6, 13.6, for L^* , u^*, v^* respectively in 95% of the population. The influence of solar radiation on the skin extends this range with the ranges of the seasonal variation (Table 6.2). Then the width of the range of a color mixing system for the facial skin color should amount to $\Delta L^* = 41$; $\Delta u^* = 24$; $\Delta v^* = 17$.

Acknowledgements

Thanks are due to Prof. Dr. W.G. Zijlstra, chairman of the laboratory for Chemical Physiology for the hospitality during the bicycle ergometer experiment; to Dr. P. Rispens for supervising the bicycle ergometer experiment and for valuable discussions; to Prof.Dr. E. Bleumink for his critical comments; to Mr. R. Kroeze of Borg-Warner Chemicals for his valuable cooperation during the spectrophotometric measurement; to Drs. J.H. Lichtenbelt for the development of the overall color difference, computerized calculation programs; to Miss A. van Hoogen for typing the manuscript and to Mr. Chr. Lingeman and Mr. E. van Ommen for preparing the illustrations.

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CHAPTER 7

THE SKIN RESPONSE TO ^{60}Co IRRADIATION AND THE CONSEQUENCES FOR MATCHING THE COLOR OF FACIAL PROSTHESIS

R.P. van Oort, J. Vermey, J.J. ten Bosch

7.1. Abstract

A radiotherapy treatment (^{60}Co) of cancer in the head and neck region causes side effects in the skin, which postpones the facial prosthetic treatment of a defect in the facial region. The increasing and fading erythema and pigmentation of the skin was investigated, using a subtractive colorimeter.

This method was verified with photographs, scored according to the Oxford scoring system. Concomittantly the relative skin temperature was measured. Fourteen patients were investigated during a period of 24 weeks. The mean colorimetric skin response showed a peak of six weeks after the onset of irradiation. Six to seven weeks later on there was no significant difference between the skin color before and after irradiation. At this time the dry desquamation of the skin has healed. From this viewpoint the color matching procedure for a facial prosthesis may start not earlier than 15 weeks from the onset of irradiation. If a non-irradiated control field in the facial area is present a color match for the facial prosthesis may start just after the irradiation period.

*To be submitted for publication to the Br. J. Radiol.

7.2. Introduction

The treatment of malignant tumours in the head and neck region requires a combination of different treatment modalities in many cases. These modalities are: radiotherapy, surgery, E.N.T.-surgery, chemotherapy, plastic surgery, oral surgery and maxillofacial prosthetics.

A surgical approach of head and neck tumours may result in a mutilated defect in the facial region. Radiotherapy in combination with surgery may complicate this morbidity. A defect of the ear, nose and eye or a combination of these defects may be reconstructed surgically or by means of a facial prosthesis.

Early skin lesions produced by radiotherapy may, however postpone the facial prosthetic treatment. In the first weeks after completion of the radiotherapy course the healing of the dry- and/or moist desquamation and the fading of erythema and change in pigmentation causes delay in making a color match. The individual skin reaction pattern after megavolt irradiation may be very different and it is not known when the skin reaction reaches a relatively constant level.

The early skin reactions after megavoltage radiotherapy (^{60}Co) are described by Tessmer (1971) and Moss (1973). With a daily fractionated dose of 2 Gy/day for five days a week the skin appearance changes with increasing dosage because of increasing erythema, epilation, desquamation, pigmentation (or achromia) and capillary congestion and afterwards complete desquamation. The reparative process that follows, is associated with progressive fibrosis and vascular subendothelial hyperplasia.

The time-dose relationship based on clinical observations (Strandquist, 1944) and experiments (Fowler, 1965) shows that both the radiation dose and type of fractionation are of decisive importance for the biological effect. The maximal absorbed dose of ^{60}Co radiation lies approximately 0.5 cm beneath the skin surface (Tessmer, 1971). The cosmetic

effects on skin are epilation (after 14 days), erythema (after 21 days), loss of function and cessation of secretion of sebaceous and sweat glands (after 14-21 days) (Rubin and Casarett, 1968; Berdjis, 1971; Moss, 1973).

Turesson and co-workers evaluated skin reactions after radiotherapy with a photo-electric reflection meter (Turesson et al., 1975). Erythema and pigmentation developed concomitantly and on the whole parallel for different fractionation schemes. Nine weeks after the onset of radiotherapy the erythema and pigmentation level had returned to a constant level which was higher than the first registration. A visual method to evaluate the effects of varied numbers of dose fractions was used by Brennan (1976). He used a modification of the Oxford skin scoring system (Berry et al., 1974). To each degree of erythema, pigmentation and desquamation a numerical score was subjectively allocated. Their results showed no residual reaction twenty-four weeks after the beginning of treatment.

This paper aims to quantify instrumentally the patterns of increasing and declining early skin reactions and to determine the earliest moment for facial prosthetic treatment. Concomitantly the measurement of the skin temperature was performed.

7.3. Materials and methods

Twenty-two patients with squamous cell carcinoma in the head and neck region were irradiated pre- or postoperatively as described in Table 7.1. The skin dosage was calculated at about 1 mm below the skin surface (Siemens Dosieranleitung), this means 85% of the central tumour dose (Ibbott, 1970). The irradiation technique was 2 plan parallel fields or 2 wedge fields. A control field was chosen to be outside the irradiated field, but suitably close enough to the area of intended facial prosthetic therapy to have a comparable

Table 7.1

Patient	source	field$_2$ in cm	irradiation technic	overall dose 0.5 cm depth skin rad. (Gy)	overall dose 0.5 cm depth contr.skin (Gy)	disease
B.H.	^{60}Co	7x7	plan.par.	53	1	T_{1b} NoMo larynx sq. carc.
R.B.	^{60}Co	7x7	plan.par.	58	1	T_{1b} NoMo larynx sq. carc.
T.M.	^{60}Co	7x6	plan.par.	57	1	T_{1b} NoMo larynx sq. carc.
H.B.	^{60}Co	7x6	plan.par.	60	1	T_{1b} NoMo larynx sq. carc.
E.G.	^{60}Co	7x6	plan.par.	51	1	T_1 NoMo larynx sq. carc.
G.K.	^{60}Co	6x6	plan.par.	55	1	T_1 NoMo larynx sq. carc.
G.D.	^{60}Co	13x8	plan.par.	59	2	T_1 NoMo larynx sq. carc.
P.J.S.	^{60}Co	7x7 7x7	plan.par.	57	2	T_1 NoMo larynx sq. carc.
H.N.	^{60}Co	13x18 7x6	plan.par.	51	1	T_1 NoMo larynx sq. carc.
H.D.	^{60}Co	16x13	plan.par.	47	2	sq. carc. lip + lymf nodes - postoper.
J.V.	^{60}Co	12x9	wedge	55	2	sq. carc. lip + lymf nodes - postoper.
H.L.	^{60}Co	9x12	wedge	56	2	sq. carc. tongue + lymf nodes-postoper.
M.B.*	8 MV	3x3.5	plan.par. + wax mould	61	<0.1	basal carc. dorsum nasi
B. v.d.V.	^{60}Co	3x3.5	plan.par. + wax mould	60	<0.1	sq. carc. septum nasi

*Pat. M.B., with wax mould the 100% isodose line lies at 0.5 cm depth below the surface (comparable with ^{60}Co irradiation)

histologic structure and exposure to the environment. One patient was irradiated by 8 MV x-rays, with a wax mould. The scattered irradiation of the control skin was calculated from measured beam profiles specific for the Gammatron ^{60}Co unit (Kruize, 1977). Thirteen male patients and one female patient were in the age range from 37-84 years with a mean and median of 64 years.

They were measured colorimetrically once a week during the radiotherapy course and every three weeks in the follow-up period during eighteen weeks. The biological variation of the control skin color before irradiation of this relatively small selected sample was only for the L^* significantly different from the comparable biological variation of a caucasion population (Table 7.2)(Van Oort, et al., 1981). Another eight patients were eliminated from the investigated sample because of lack of cooperation in the follow-up period (3), operation in the follow-up period (3) or death due to metastases (2). They were excluded from the results.

For the colorimetric measurements we used a Lovibond MK III (Tintometer Ltd, Salisbury, G.B.) with a movable measuring head connected with fibre optics of 2 m in length. The pressure on the skin was constantly low (Van Oort et al., 1981). All subtractive colorimetric observations were done by the first author.

The Lovibond is a subtractive colorimeter. The instrumental values are computed in CIE 1931, x, y (chromaticity coordinates) and Y (luminance factor) and from these values the L^*, u^*, v^* , color coordinates in the CIE (1976) Uniform Color Space are computed. For the presented range of colors, L^* is related to brightness perception, the u^* index is related to redness (positive) versus greenness (negative) perception, and the v^* index is related to yellowness (positive) versus blueness (negative) perception. Color differences between two color measurements were calculated in ΔE^*_{uv} (Wyszecki, 1978), by means of $\Delta E^*_{uv} = (\Delta L^{*2} + \Delta u^{*2} + \Delta v^{*2})^{\frac{1}{2}}$.

The subjects sat upright in a dental chair with the left arm in a horizontal resting position. The skin color observations were respectively taken at the radiotherapy skin region, the control field and the inner side of the forearm. The temperature of the microclimate of the measurement room was $20^{o} \pm 1^{o}$ C and the subjects were allowed to acclimatize for at least 10 minutes.

In addition, the patients were photographed every day of measurement. The views were taken from frontal left, right and half-profile positions respectively. The Agfachrome professional 50 S diapositives were taken at constant distance of 450 mm from the eyes of the subjects, with a lensopening of f/22 (105 mm objective). Two electronic flashes (Monolite 400 E) were used at equidistant from the chair. The films were processed by a commercial laboratory (Capilux).

The skin response was assessed visually by two observers according to the Oxford skin scoring system from the slides (Berry et al., 1974). The three slides taken from the three directions, in the course of the investigation, were projected by three Leitz pradovit Color 250 projectors (120 mm objective) in a medium dark projector room for scoring.

The skin temperature was measured every day of measurement by means of an Ellab A-S temperature meter, type du-3 S with a thermo-couple probe (type A-H1).

The differences of the means were compared by the Student's t-test at a 95% level of significance. The differences in standard deviations were studied by the F-distribution test at a 95% level of significance (Wesp, 1977; Clarke, 1980).

7.4. Results

Colorimetric determinations for the successive measurement intervals of the irradiated skin were averaged for 14 patients. The results in L*, u*, v*, are summarized in figure 7.1.

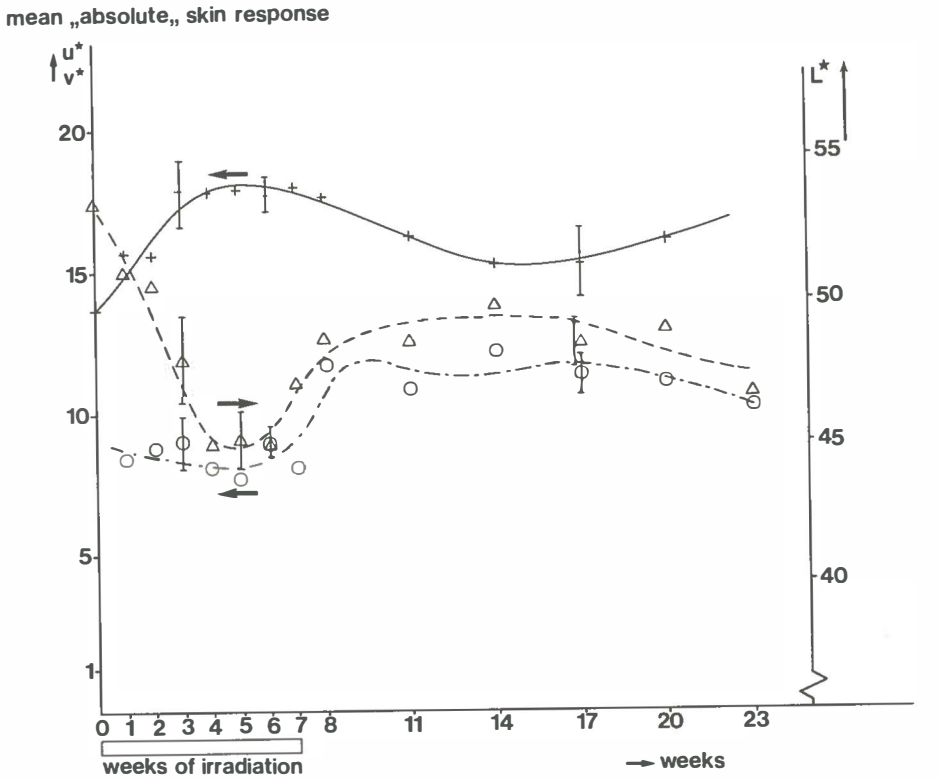

Figure 7.1
Mean value and standard errors of colorimetric measurements (L : -Δ-; u* :—+-; v* :--o-) in the irradiated skin (N=14) following treatment with ± 30 dose fractions of 1.25 MV ^{60}Co irradiation, for the group of individuals.*

These colorimetric indices reach their peak at the sixth

week from the onset of the irradiation. In the control skin no evident peak reaction was observable.

For each individual the colorimetric values during the period of measurement were calculated from off the baseline i.e. the initial value before irradiation. The colorimetric values from the baseline for each measurement step for the group of individuals were averaged (Fig. 7.2). The same procedure was performed for the control skin in the head and neck region and forearm (Fig. 7.2).

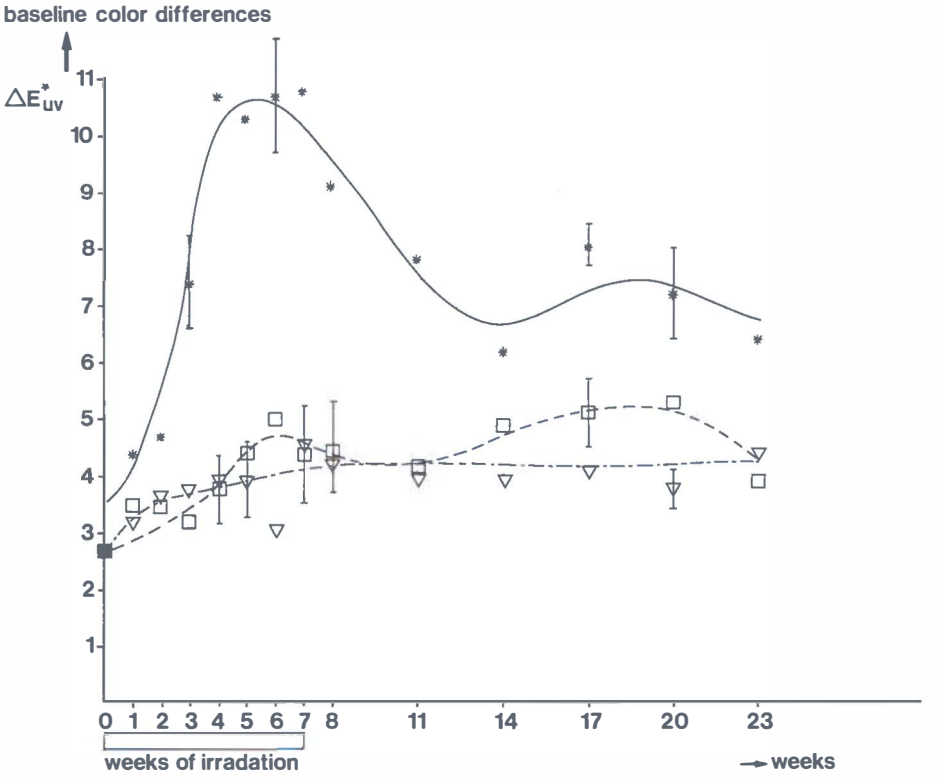

Figure 7.2

Mean values and standard errors of color differences ΔE_{uv} for each measurement step against the initial value at the beginning of treatment, of the irradiated skin (-✱-), the facial skin outside the irradiated region (-□--) and the inner side of the forearm (-▽--). The initial value ■ (ΔE=2.75) corresponds to the short term variation of the skin color.

The peak reaction was reached in the sixth week from the beginning of treatment. Between the third and twelfth weeks there is a significant difference between the means of the normalized color differences of the irradiated skin and the control skin, as well as forearm. It can be seen that the color difference between the initial value (baseline) and the first week of irradiation for the three skin regions is relatively high. This color difference is significantly different from the error of measurement and suggests a short term skin reaction together with a side effect of the irradiation. After 24 weeks the values have not returned to the initial value. For the irradiated skin the skin reaction subsides to lower levels after a peak at week six. Between the twelfth and fifteenth week, the skin color is significantly different from the peak value. In the end there is a constant level for $\pm$ 10 weeks at least.

Separate measurements were made to differentiate between the error of measurement, the irradiated skin color variation and the biological variation. The precision of measurement was determined in eight subjects with three successive measurements. The combined standard deviation was calculated. Table 7.2. gives the values in comparison with the biological variation before irradiation and the standard deviation of the irradiated skin.

Table 7.2. Combined standard deviations of the irradiated group of patients (N=14), before irradiation, caused by the irradiation. Both compared with the precision of measurement in the population.

	d.f	SD_{L^*}	SD_{u^*}	SD_{v^*}
precision of measurement	9	1.1	0.5	0.9
total variation in irradiated skin	128	4.0	3.1	2.5
biological variation before irradiation	13	5.5	4.1	2.9
caucasian population Van Oort et al.,1981	99	7.4	3.4	3.4

The peak changes and the residual color difference at week 24 are shown in Table 7.3. The ΔE^*_{uv} of the peak reaction as well as for the twentyfourth week was averaged from the baseline on the basis of the initial value.

Table 7.3. Mean and standard error of the baseline color difference ΔE^*_{uv} on the basis of the skin color before irradiation for 14 subjects after 6 and 12 weeks.

irradiated skin	ΔE^*_{uv}	ΔL^*	ΔU^*	ΔV^*
6^{th} week peak skin reaction	10.7±4.0	7.4±4.5	4.7±4.6	3.5±2.8
24^{th} week residual skin reaction	6.4±3.2	4.6±3.8	3.0±2.0	2.0±1.3
control skin				
6^{th} week peak skin reaction	5.0±3.4	2.1±2.2	2.9±1.5	N.S.
24^{th} week residual skin reaction	3.9±3.2	1.9±1.3	N.S.	N.S.

Student's t-test N.S. = non significant

In order to eliminate climatic, physical and physiologic influences on the irradiated skin, the color of the control skin was subtracted from the color of the irradiated skin color. The mean color differences of L^* , u^* , v^* and the combination in ΔE^*_{uv} (Fig. 7.3) show the peak somewhat earlier in the fifth week. The dominance of the L^* (pigmentation equivalent) reaction of the skin in comparison to both chromaticity coordinates (erythematous equivalent) is shown. The residual pigmentation is evident.

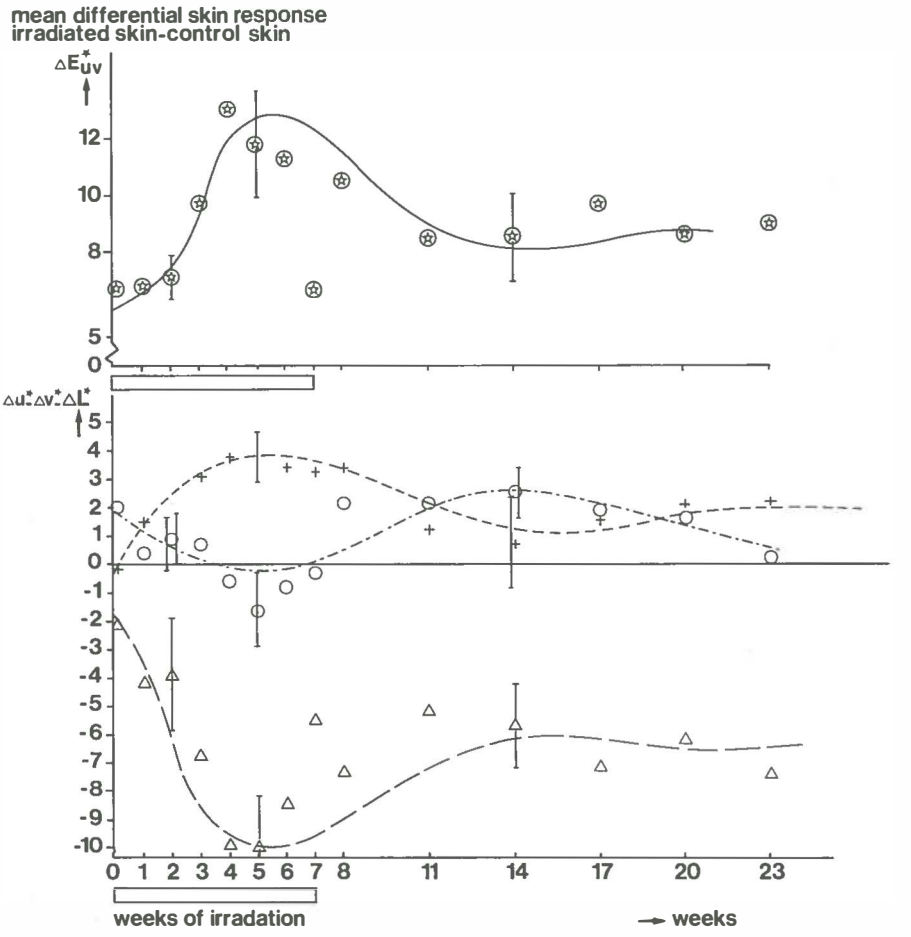

Figure 7.3

Mean values and standard errors of color differences of the irradiated skin against the facial skin outside the irradiated field (ΔL : -Δ-; Δu* : -+-; Δv* : -o-; ΔE^*_{uv} : -⊛-) (N=14).*

The mean temperature of the irradiated skin and the visually scored skin response (Oxford skin scoring system) are shown in figure 7.4.

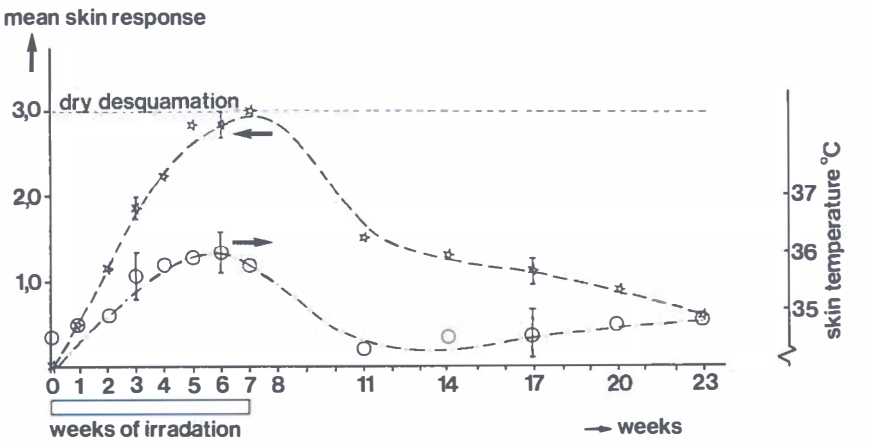

Figure 7.4
Mean numerical skin scores and standard errors (Oxford system) against the time from the beginning of treatment (-☆-). The mean values and standard errors of skin temperature (-o-) is measured with a thermo couple probe and Ellab A-S measuring instrument (N=14).

The elevated skin temperature during irradiation coincides with the peak skin reaction. In the post-irradiation, follow-up, period there is no significant difference in skin temperature between the irradiated skin and the control skin.

7.5. Discussion

The results of the colorimetric skin color measurements of Megavolt (gamma) irradiated skin are evident. After the peak the skin reaction returns to a lower, relatively constant, level between the twelfth and fifteenth week after the beginning of irradiation (Fig. 7.1, 7.2).

The standard errors of the results are mainly due to variations in the response to irradiation from patient to patient. This is in agreement with the findings of Turesson (1975) with 13 MV irradiation.

The similarity of the results between the colorimetric method and the Oxford scoring system, analyzed by two observers on the slides is observable in figures 7.2 and 7.4.

The residual discoloration between the beginning of irradiation and twenty-four weeks later is shown in Table 7.3 and figure 7.2. The means of residual pigmentation in our results caused by 1.2 MV irradiation are not significantly different from the initial skin color values (Fig. 7.2). These results are not in contradiction with the results of Brennan (1976), who found a higher amount of residual pigmentation. He observed skin reactions of 125 KVP irradiation, which has no skin sparing effect.

The results in the control skin measurements indicates a scattering effect in discoloration with the irradiated skin (Fig. 7.2), which slowly declines with time. Simultaneously the forearm shows an almost constant level of skin color. This demonstrates the effect of scattered irradiation on the control skin outside the irradiated field (Table 7.1).
The color difference between the beginning of irradiation and the end of the first week is caused by different factors: a short term vascular effect (van Oort, Ten Bosch, 1981), a prohibition to shave and wash the irradiated field, and a general physical discomfort.

The initial color difference before irradiation between the irradiated field and the control field (Fig. 7.3) is

explained by the different skin colors of the irradiated field (the neck in 9 subjects; a pre-irradiated operation region in 3 subjects) and the skin color of the control field in the facial region.

The differing skin reaction of the irradiated skin compared with the control skin (Fig. 7.3) is caused by the contributed value of ΔL^* with a minor contribution of Δu^*. This suggests a large variation in observed brightness perception of the skin, caused by the increasing amount of desquamation and pigmentation.

Irradiation causes an elevation of skin temperature (Fig. 7.4) which is also described by Moss (1973).

These findings lead to the following consequences. The clinician wants to rehabilitate the patient prosthetically as soon as possible. It has been shown that the inner forearm is not suitable for color matching in the face (van Oort et al., 1981). Our findings indicate, that it is possible to match the color of the prosthesis to a non-irradiated control field in the face, if the initial color difference between the two skin regions is small. In practice this can be done just after the irradiation period. If such a field is not available, than the color matching has to wait until the fifteenth week from the onset of irradiation (Fig. 7.2).

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CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1. Statement of the problem

The treatment of neoplasms, maxillofacial traumas and congenital malformation may result in a serious disfigurement of the patients face. A person with a facial defect may be the subject of psychological and social problems, because of the importance of the face in interpersonal relationships.

The treatment modalities of facial reconstruction are: a reconstruction by plastic surgery or a facial prosthetic treatment of the defect. The plastic surgery reconstruction is the method of choice in the reconstruction of a disfigured face, but can have contra-indications because of anatomical or pathological reasons.

The matching of color is of major importance in facial prosthetic reconstruction. The well known color matching methods are time-consuming, are difficult to reproduce and are based on subjective color matching. An objective color measuring method should be developed to put skin color matching on a more scientific basis, by an instrumental color measurement and the formulation of a matching base color with an elastomer as base material.

The aim of this investigation is to determine objectively the range of the facial skin colors for a skin color reproducing system. In this system the complex color changes caused by the dynamic nature of skin should be included.

A recently published evaluation report, supports the importance of such a system (Chen, et al., 1981).

8.2. Summary and conclusions of this investigation

In the introduction to this study, the outline of the problem of disfigurement for the patient as well as the physician is briefly discussed and the aims of this investigation are described.

In chapter 2 the incidence of facial prosthetic treatments and the psychosocial aspects of facial disfigurement are described (Table 2.1). The appearance of the prosthesis is determined by its form, texture and color. The current prosthetic technology in the restoration of form, texture and color is outlined. It is concluded that the reproduction of color in the facial prosthesis and the prevention of staining by external factors need improvement.

The main physical, physiological and psychological factors which play a role in the perception of objects are described in chapter 3. The measurement of color and color difference requires a quantitative system in which a physically measurable property of an object is related to its perceived color. In this selected L^*, u^*, v^* space the numerical differences in coordinates of the space yield approximately uniform relationships with perceptual color differences (L^* is related to brightness, the u^* index is related to redness (+) versus greenness (-) and the v^* index is related to yellowness (+) versus blueness (-)). A method of measurement has been selected and for practical and economical reasons the Lovibond MK III was chosen.

In chapter 4 the appearance relevant properties of skin have been described. The appearance of the skin is determined by the incident light, the structure of the surface, the excretion of the sebaceous- and sweat glands, the chromophoric elements in the skin and the degree of scattering in the epidermis and dermis. The histological changes of the

skin caused by photobiological and physiological factors have been described. No quantitative data are available for a population concerning the degree and range of variation of the skin color of the face.

In chapter 5 an epidemiological investigation of the skin color of subjects has been described in the north of the Netherlands. The subjects were measured on the palm of the hand, the inner forearm and the cheek. The measuring head of the subtractive colorimetric measurer (Lovibond MK III) was placed on the skin by means of a constant force balance. This method ensures that the pressure on the skin never exceeds the subcutaneous capillary blood pressure. Calibration measurements by means of a spectrophotometric method (Zeiss RFC-3) showed that skin color measurements are comparable between the Lovibond MK III and the Zeiss RFC-3, if the measuring test areas of both methods should be approximately equal. The measuring test area of 15 mm as well as 30 mm using the Zeiss RFC-3 showed an increasing divergence in colorimetric values (Table 5.2) from the subtractive color measurement (5 mm measuring test area). In a random (systematic) sample of 100 subjects the range (95%) and the mean of the distribution of the facial skin colors is analysed. Correlations of the skin color indices between the three measured regions were not statistically significant (Table 5.5). This means, that the color of the prosthesis should only be matched with the surroundings of the prosthesis bearing areas.

Chapter 6 contains a description of the quantitative skin color variations due to photobiological and physiological factors. In a first sample of thirteen persons the facial skin was measured every three weeks during one year. The overall skin color variations were computed for every subject and averaged for the whole sample. In a second sample of thirteen subjects the physiological influences on the facial skin color were measured by means of a bicycle ergometer test and for eight of these by a cooling experi-

ment (4^{o} C). The mean facial skin color variation due to photobiological factors is about twice as large as that caused by vascular changes (Table 6.3 and figure 6.4, 6.5).

The standard errors of the measurements of the facial skin color variations in the muscular work and cooling experiments were large. These experiments mean that the extension of the range of the color mixing system under these conditions is likely to be unreliable. The color system is extended due to the photobiologic skin color variations (Table 6.2). In addition an analysis was performed of the photobiological skin color variations. After determination of the short term skin color variation, taking the error of measurement into account, the photobiological skin color variations seems to be caused by alterations in the skin which influence the L^* color index mainly and the u^* color index to a lesser degree (Table 6.2 and Fig. 6.2). This finding is confirmed by the spectrophotometric skin color measurements of one group of subjects in wintertime and a second one in summertime (Table 6.4 and Fig. 6.3). Consequently, the seasonal dependent variations of the facial skin color is added to the fabrication of a prosthesis by making a second prosthesis with L^*-u^* altered color formulation, or by the external addition of melanin type pigments to the lighter colored wintertime prosthesis. Such adjuvants pigments are essentially grey.

In chapter 7 the quantitative skin color changes which result from ^{60}Co radiotherapy treatment are described. During 6 months the irradiated skin and adjacent facial skin regions of 14 patients were measured colorimetrically. Furthermore the morphologic skin changes were observed by means of color photographs. The colorimetric skin changes and morphologic alterations showed that a color match is possible on average thirteen weeks after the onset of irradiation. The change of the skin color variation after thirteen weeks compared with the baseline measurement does not extend the range of the color mixing system.

Summarizing, in this investigation the width of the range of facial skin for the population in the north of the Netherlands is determined ($P < 0.05$). Insight has been obtained into variations in facial skin color. It has been shown that photo-biologic factors influence the facial skin to such amount, that it determines the width of the range of the color mixing system as well.

8.3. Indications for extended investigation

Sufficient knowledge has been developed into the facial skin colors to begin the construction of a color system. The next phase will be the development of the color formulating system. This means the formulation and composing of different matching base colors from a base material with suitable proportioning pigments. The subtractive colorimetric method is unsuitable for color formulation. Spectrophotometric reflection measurements in the measurement of the scattering coefficient of the skin according to Groenhuis (1981) are suitable in this prospect. The spectral reflectance curve and the scattering coefficient, obtained by these methods, can be used for the calculation of the ratio of pigments. Calculation programs to do this are available in the synthetic material industries. This information results in a number of base colors which cover the range of the colors of the face and result in improved esthetics of the facial prosthesis, which result in positive effects on the esthetics of the facial materials, the reproducibility and the cost-benefit account. Further investigations are necessary to improve the quality of the facial prosthetic materials and skin adhesives. Eventually, it is important for the facially disfigured patients to improve their psychosocial rehabilitation, being a part of the multidisciplinary treatment programs. Research in this field is recommended.

For referrences see p. 148.

SAMENVATTING EN CONCLUSIES

Probleemstelling

Ten gevolge van de verwijdering van een tumor, door een ongeval of door een aangeboren afwijking kunnen mensen gehandicapt worden door een ernstige misvorming van het gelaat. Een persoon met een gelaatsdefect kan hierdoor psychologische en sociale problemen ondervinden. Immers het gelaat vormt het centrum van aandacht in het sociale verkeer.

De reconstructie van een gelaatsdefect kan geschieden door middel van een plastisch chirurgische correctie met lichaamseigen weefsel of een gelaatsprosthetische behandeling met behulp van weefsel vervangend materiaal. De eerste behandelingsmethode verdient in het algemeen de voorkeur, vanwege de verhoogde kans op acceptatie van de behandeling door de patiënt. Deze chirurgische correctie is echter niet altijd mogelijk vanwege anatomische of pathologische redenen.

Bij de prothetische behandeling van een gelaatsdefect zijn de vorm en de kleur van de prothese van groot belang. De reeds bekende methoden voor het reproduceren van de huidskleur zijn tijdrovend, niet reproduceerbaar en gebaseerd op een subjectieve wijze van kleurbepaling en kleurvervaardiging. Er bestaat grote behoefte om deze wijze van kleurreproduktie te vervangen door een meer objektieve methode om de kleur van het gelaat te bepalen, met het doel deze reproduceerbaar te kunnen imiteren in een bij voorkeur elastische kunststof.

Doel van dit onderzoek is het objectief meten van de huidskleur van het gelaat. Het vastleggen en inventariseren

van de verschillende kleuren van de huid van het gelaat. Een tweede doel is het vaststellen van de mate waarin de voornaamste externe- en interne factoren invloed hebben op de kleur van de huid. Deze gegevens vormen dan de basis voor de omvang van een kleursysteem, waarmee zoveel mogelijk huidskleuren van een bevolkingsgroep kunnen worden vervaardigd. In een recent evaluatie onderzoek wordt het belang hiervan ondersteund (Chen, et al., 1981).

Samenvatting en conclusies van dit onderzoek

De problematiek van een gelaatsdefect voor de patiënt zowel als voor de behandelaar wordt geschetst en het doel van dit onderzoek wordt beschreven in hoofdstuk 1.

In hoofdstuk 2 wordt aan de hand van de frequentie van voorkomen van de faciale prothese behandelingen (Tabel 2.1) en de psychosociale aspecten van de gelaatsgehandicapte de omvang van het probleem aangegeven. De vorm, oppervlaktestructuur en kleur van het gelaat bepalen de vormgeving van de prothese. De huidige stand van zaken in de prothese technologie met betrekking tot de vormgeving wordt beschreven. Het reproduceren van de huidskleur in het prothese materiaal en het optreden van materiaalverkleuring als gevolg van externe invloeden komen voor verbetering in aanmerking.

De voornaamste fysische, fysiologische en psychologische factoren welke een rol spelen bij het visueel waarnemen van objecten worden beschreven in hoofdstuk 3. Het meten en vergelijken van kleuren vereist een kwantitatief systeem, waarin de relatie tussen de fysische prikkel en het waargenomen effect wordt vastgelegd. In de gekozen L*, u*, v* schaal sluiten numerieke kleurverschillen aan bij visueel waargenomen kleurverschillen in helderheid en chroma (L* is een maat voor de waargenomen helderheid; u* is een maat voor de waargenomen rood (+) of groen (-) kleur; v* is een maat voor de waargenomen geel (+) of blauw (-) kleur). Voor het vast-

leggen van kleur en kleurverschillen is uit praktische en financiële overwegingen de Lovibond MK III gekozen.

In hoofdstuk 4 wordt aan de hand van een literatuurstudie het uiterlijke aspect beschreven van de huid als een dynamisch, variabel orgaan, welke uit meerdere lagen bestaat. Het uiterlijke aspect van de huid wordt bepaald door de samenstelling van het opvallende licht, de structuur van het oppervlak, de excretie produkten van de huid, de chromophore elementen in de huid en de mate van verstrooiing in de epidermis en de dermis. De histologische veranderingen van de huid ten gevolge van fotobiologische en fysiologische factoren zijn globaal bekend. Er zijn echter geen kwantitatieve gegevens bekend over de mate van verandering van de huidskleuren en de omvang van het huidskleurgebied van de populatie.

In hoofdstuk 5 wordt een epidemiologisch onderzoek beschreven van de huidskleuren, welke in het noorden van Nederland kunnen voorkomen. De bepalingen geschiedden op de palm van de hand, de binnenzijde van de arm en op de wang. De meetkop van de subtractieve colorimetrische meetmethode (Lovibond MK III) werd met een constante drukveer op de huid geplaatst. De druk van de meetkop op de huid was dan niet groter dan de subcutane capilaire bloeddruk.

Calibratiemetingen met een spectrofotometrische methode (Zeiss RFC-3) toonden aan, dat de kleurwaarderingen van de huid vergelijkbaar zijn wanneer althans de meetopening bij beide methoden ongeveer gelijk is. De spectrofotometrische meetopening van 15 en 30 mm Ø liet een toenemend verschil van de colorimetrische waarden zien (Tabel 5.2) ten opzichte van de subtractieve kleurmeting (5 mm Ø). Uit een systematische aselecte steekproef van 100 personen werd de breedte en het gemiddelde van het huidskleurgebied van de wang aangegeven van de populatie ($P < 0.05$). De colorimetrische waarden van de huidskleuren van de drie huidgebieden hebben onderling geen correlatie (Tabel 5.5). Voor het samenstellen van de prothesekleur kan derhalve geen gebruik

worden gemaakt van kleurmetingen die op andere, eenvoudig bereikbare, huidgebieden zijn verricht.

Hoofdstuk 6 bevat een beschrijving van de kwantitatieve huidskleurvariaties ten gevolge van fotobiologische en fysiologische factoren. Bij een eerste groep van dertien personen werd gedurende 1 jaar iedere 3 weken de huidskleur gemeten. De maximaal gemeten huidskleurveranderingen per persoon werd berekend evenals een gemiddelde voor de hele groep.

De fysiologische invloeden op de gelaatskleuren werden bepaald met behulp van een fietsergometer test bij een tweede groep van 13 personen en een koelcelexperiment (4^{o} C) bij 8 personen van deze tweede groep. De gemiddelde huidskleurverandering van het gelaat ten gevolge van fotobiologische factoren is ongeveer twee keer zo groot als ten gevolge van uitsluitend vasculaire veranderingen (Tabel 6.3 en Fig. 6.4).

De standaardfouten van de huidskleurmetingen bij de beide temperatuurregulatie experimenten geven geen aanleiding tot een uitbreiding van het gelaatskleurgebied voor een kleursysteem (Fig.6.4, 6.5). Het kleursysteem wordt wel uitgebreid als gevolg van fotobiologische huidskleurveranderingen (Tabel 6.2).

Voorts werd een analyse gemaakt van de fotobiologisch veroorzaakte huidskleurveranderingen. Na het bepalen van de huidskleurveranderingen op korte termijn, met inachtneming van de meetfout, blijken deze veranderingen te zijn veroorzaakt door veranderingen in de huid welke de L* en in geringere mate de u* kleurindices beïnvloeden (Tabel 6.2 en Fig. 6.2). Dit wordt bevestigd door de spectrofotometrische huidskleurbepaling van twee groepen mensen waarvan één in de winter en de tweede groep in de zomer werd gemeten (Tabel 6.4 en Fig. 6.3). Deze seizoens afhankelijke veranderingen van de huidskleur kunnen aan het kleursysteem worden toegevoegd door het vervaardigen van twee prothesen waarvan één in de zomer en de ander in de winter wordt gebruikt. Een andere mogelijkheid is om een prothese aangepast aan de

winterhuidskleur door toevoeging van melanine-achtige pigmenten te wijzigen in de zomer-huidskleur. Dergelijke pigmenten zijn in hoofdzaak grijs gekleurd.

In hoofdstuk 7 worden de kwantitatieve veranderingen bij ^{60}Co bestraling in het hoofd-halsgebied beschreven. De bestraalde huid en een huidgebied buiten het bestralingsveld van 14 patiënten, werden gedruende een half jaar colorimetrisch gemeten. Daarnaast werden morfologische huidveranderingen vastgelegd door middel van kleurenfoto's. De kleurveranderingen en morfologische veranderingen tonen aan, dat gemiddeld dertien à veertien weken vanaf het begin van de bestraling een kleurenaanpassing kan worden gemaakt (Fig. 7.2). Dit is het stadium waarin de huidskleur min of meer stabiel is geworden. De gevonden huidskleurveranderingen na de dertiende week ten opzichte van het begin geven geen aanleiding tot een uitbreiding van het kleursysteem.

Samenvattend kan worden gesteld dat in dit onderzoek de omvang van het gelaatskleurgebied met een betrouwbaarheid van 95% werd vastgesteld voor de bevolking van het noorden van Nederland. Meer inzicht werd verkregen in de veranderingen van de gelaatskleur. Het is gebleken, dat alleen fotobiologische factoren de gelaatskleuren zodanig beïnvloeden dat deze de grenzen voor een kleursysteem voor de gelaatsprothetiek mede bepalen.

Aanbeveling voor verder onderzoek

Nu er door dit onderzoek inzicht is verkregen in het huidskleurgebied voor een prothese kleursysteem is de volgende fase het overbrengen van de gemeten huidskleur op een identieke prothesekleur. Dit betekent het samenstellen van een aantal basiskleuren met behulp van daarvoor geschikte pigmenten en een basis materiaal (kleurreceptuur), zodanig dat geen of slechts een geringe externe kleuring nodig is voor een identieke huidskleur. Voor kleurreceptuur metingen is de subtraktieve colorimetrische meetmethode ongeschikt. Spectrofotometrische reflectie metingen van het gelaat en het bepalen van de verstrooiingscoefficient volgens de methode beschreven door Groenhuis (1981) zijn daarvoor wel geschikt.

De met deze methode verkregen spectrofotometrische reflectiecurve en verstrooiingscoefficient kunnen dan worden ingevoerd in pigment concentratie berekeningen. Kleurreceptuur programma's voor dat doel zijn aanwezig en beschikbaar in de kunststofindustrie. Toegepast in de prothetiek kan deze werkwijze leiden tot een aantal basiskleuren welke het vastgestelde huidskleurgebied zo volledig mogelijk dekken, met positieve effecten op de esthetiek van de gelaatsprothese, de reproduceerbaarheid en de kosten factor. Ook de kwaliteit van de prothesematerialen op zich en van de huidadhesieven kan nog aanzienlijk worden verbeterd.

Tenslotte is het in het belang van de gelaatsprothesepatiënt te streven naar een optimale vorm van psychosociale begeleiding als uitbreiding van de multidisciplinaire behandeling van deze patiëntengroep. Onderzoek op dit terrein is derhalve aanbevolen.

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